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Xin

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(45) Date of Patent: Oct. 18, 2016

(54) **METHOD FOR PARTITIONING, MANAGING AND DISPLAYING A COLLABORATION SPACE AND INTERACTIVE INPUT SYSTEM EMPLOYING SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 72 days.

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(51) **Int. Cl.**

G06T 11/60	(2006.01)
G06T 1/60	(2006.01)
G06T 11/20	(2006.01)
G06T 9/40	(2006.01)

(52) **U.S. Cl.**

CPC .. ***G06T 1/60*** (2013.01); ***G06T 9/40*** (2013.01)

(58) **Field of Classification Search**

CPC G06T 17/20; G06T 17/205; G06T 15/04; G06T 11/40; G06T 15/005

See application file for complete search history.

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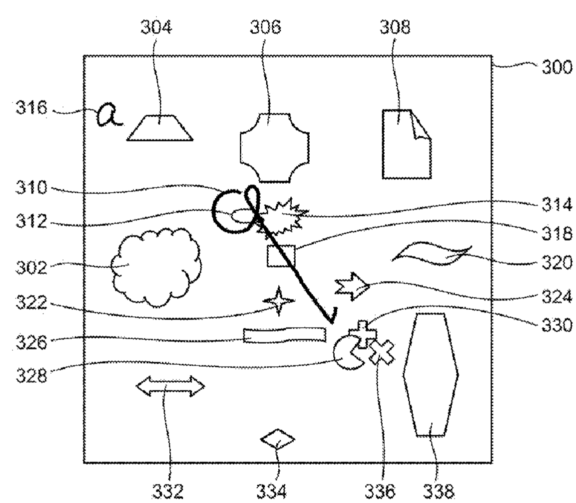
Primary Examiner — Todd Buttram

(74) *Attorney, Agent, or Firm* — Parlee McLaws LLP (CGY); Sean Goodwin

(57) **ABSTRACT**

A computerized method of managing a collaboration space comprises partitioning the collaboration space into a plurality of tiles in a tree structure; and associating each graphic object with a tile in said tree structure; said tile being the smallest tile in the tree structure that substantially accommodate said graphic object.

15 Claims, 20 Drawing Sheets



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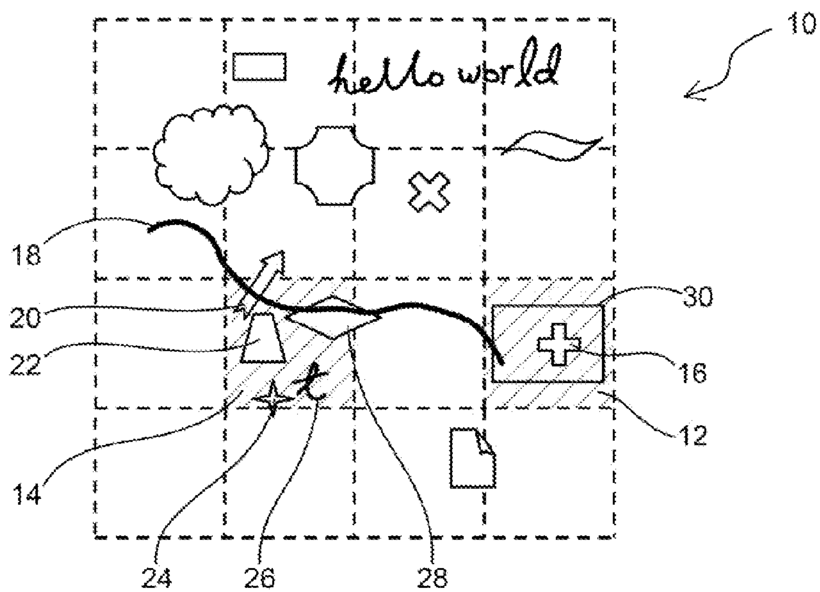


FIG. 1 (Prior Art)

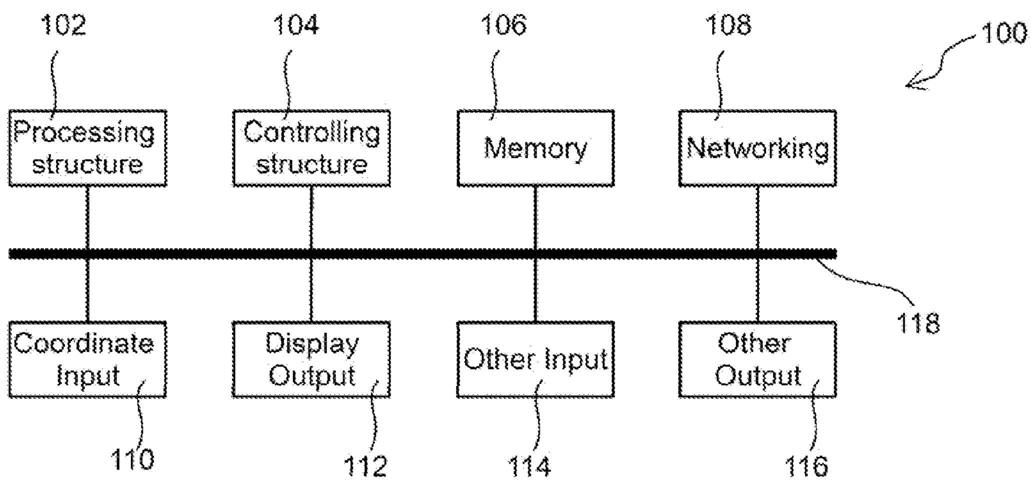


FIG. 2

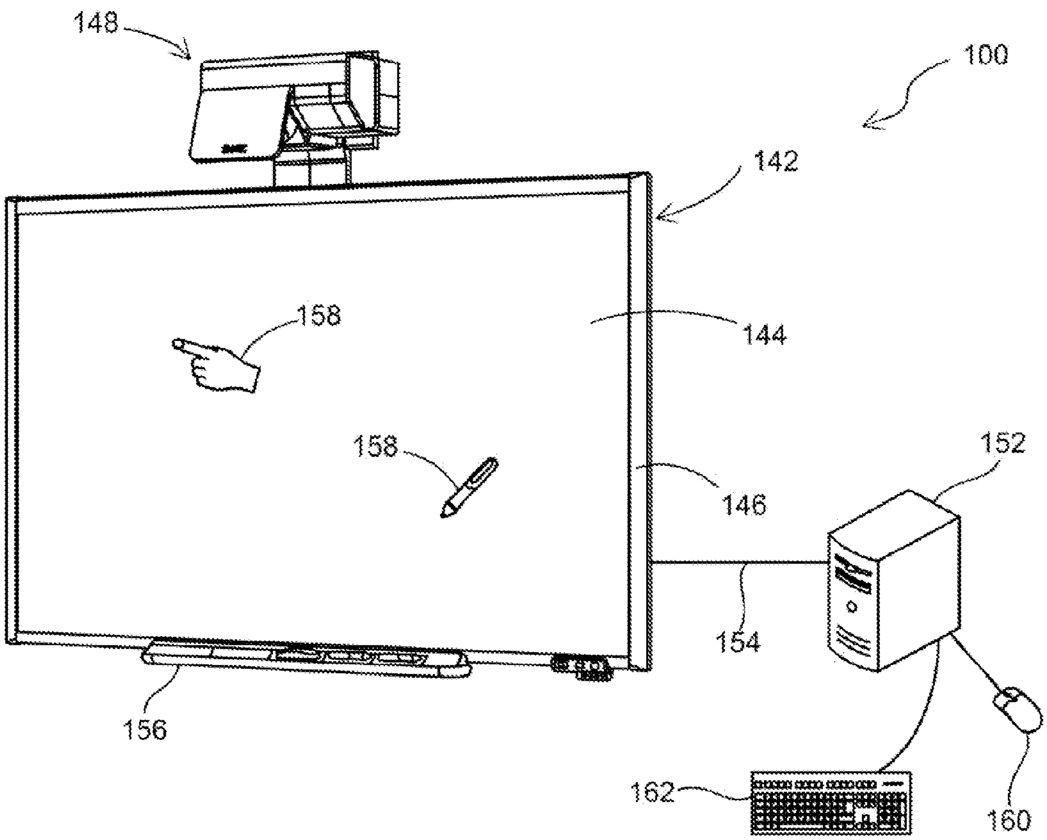


FIG. 3

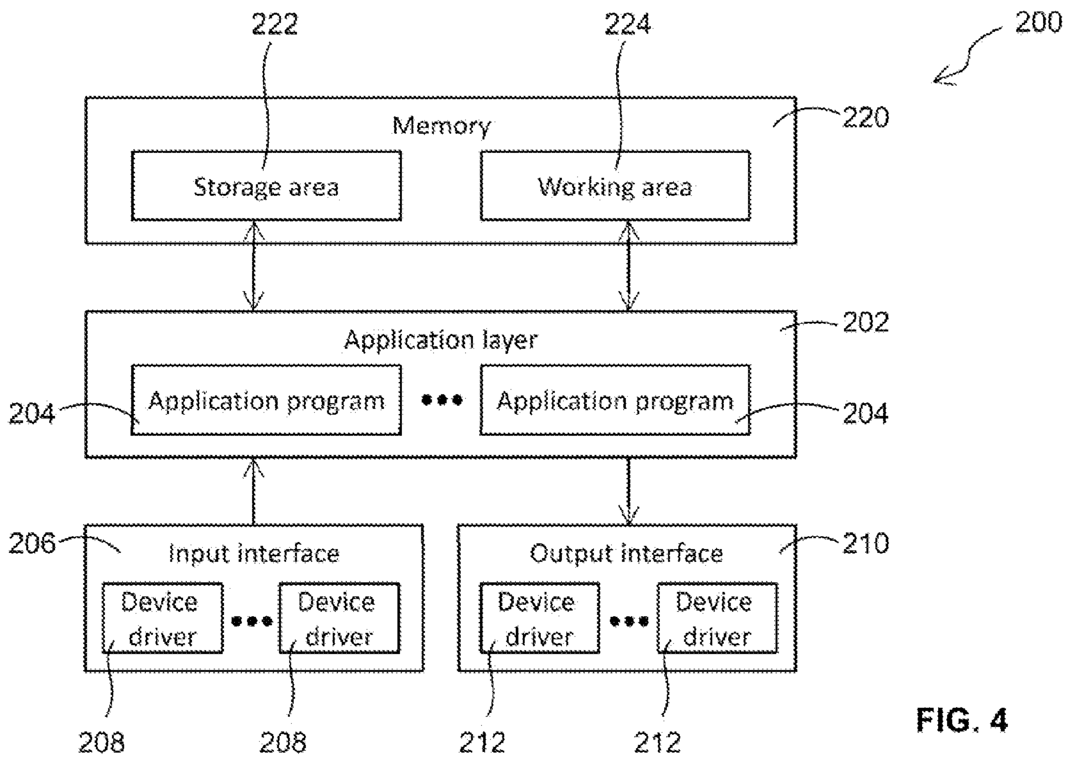

200
222
224
Memory
220
Storage area
Working area
Application layer
202
204
Application program
Application program
204
206
Input interface
Output interface
210
Device driver
Device driver
Device driver
Device driver
208
208
212
212

FIG. 4

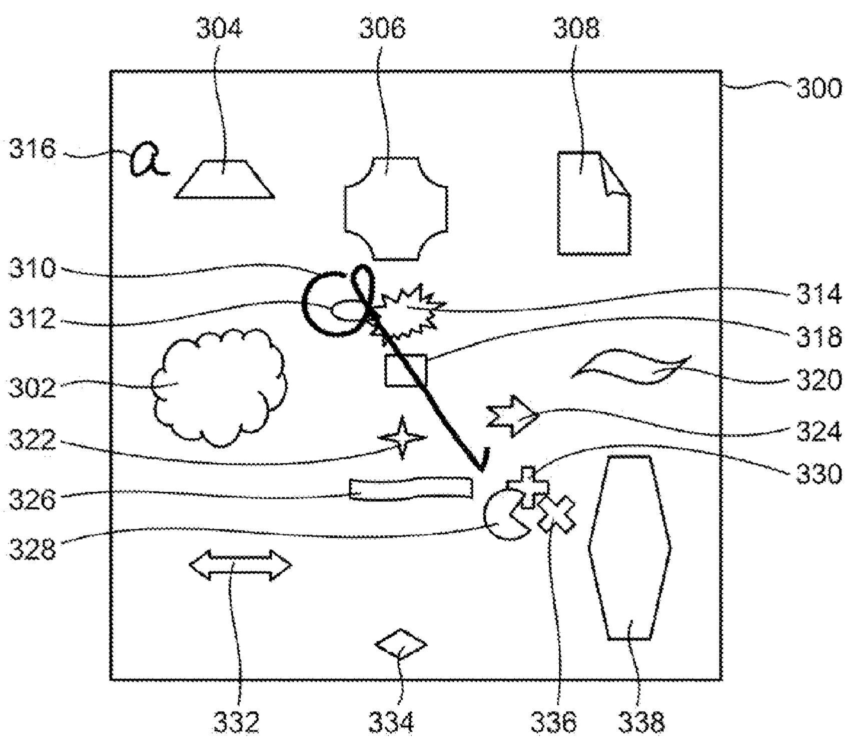

304
306
308
300
316
310
312
314
318
320
302
322
324
326
330
328
332
334
336
338

FIG. 5

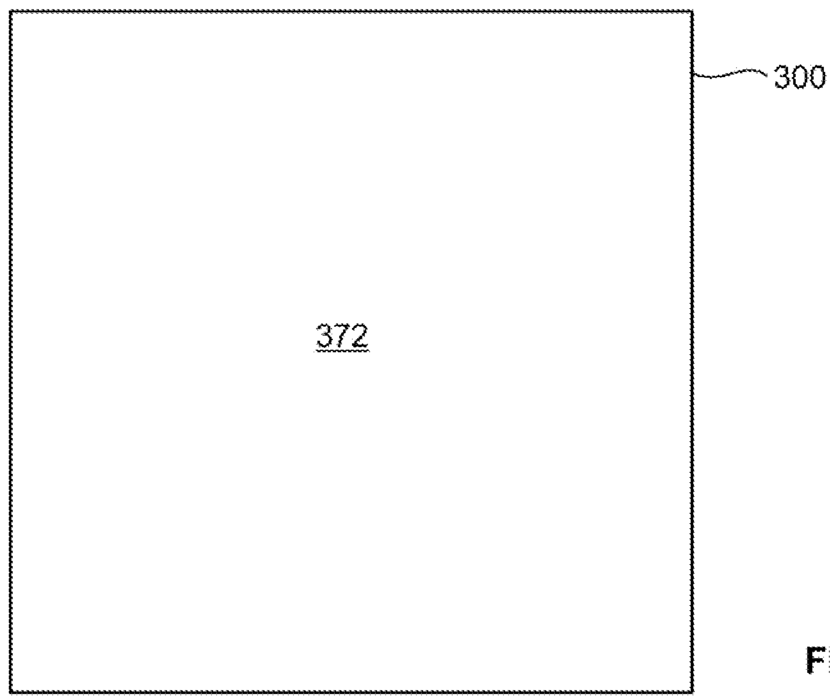


FIG. 6A

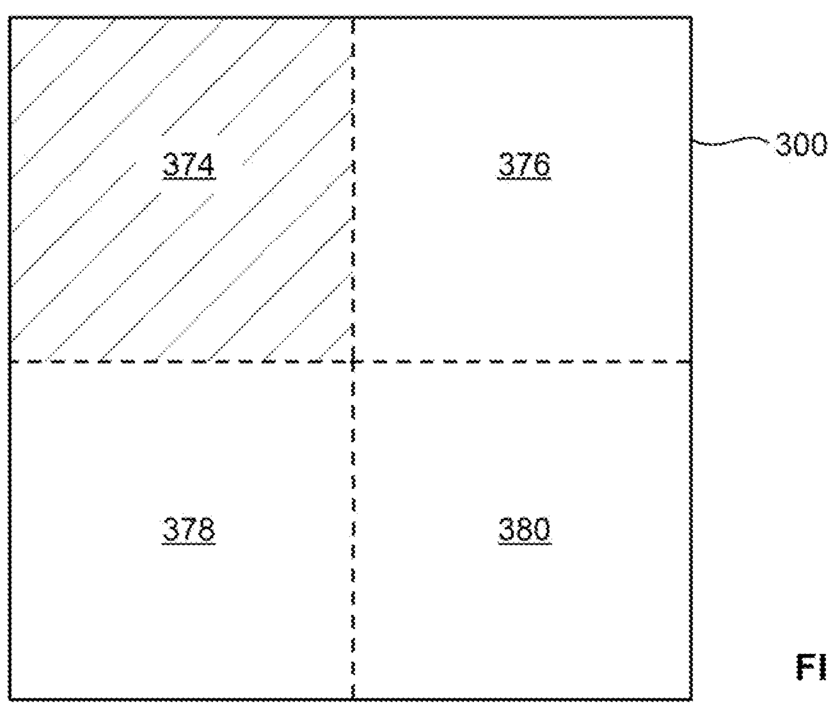


FIG. 6B

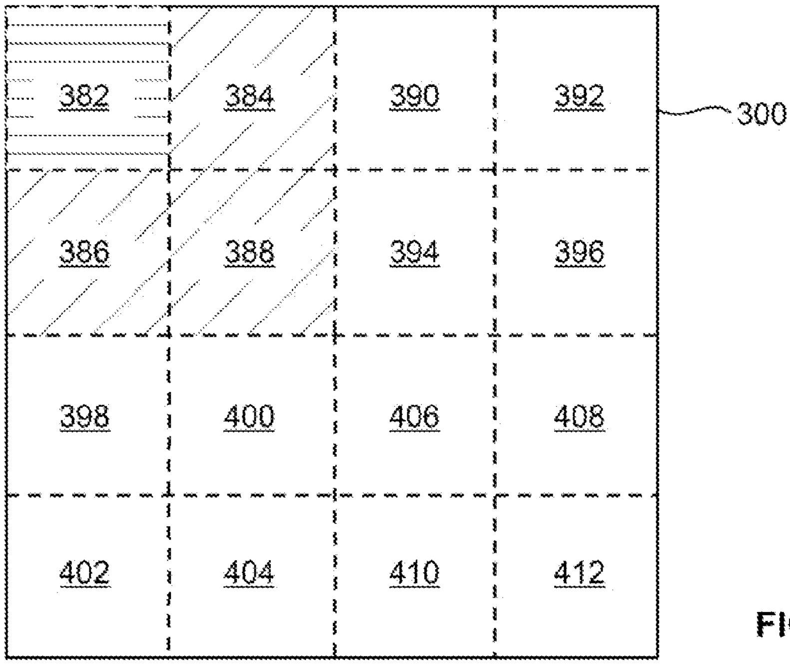

382
384
390
392
386
388
394
396
398
400
406
408
402
404
410
412
300

FIG. 6C

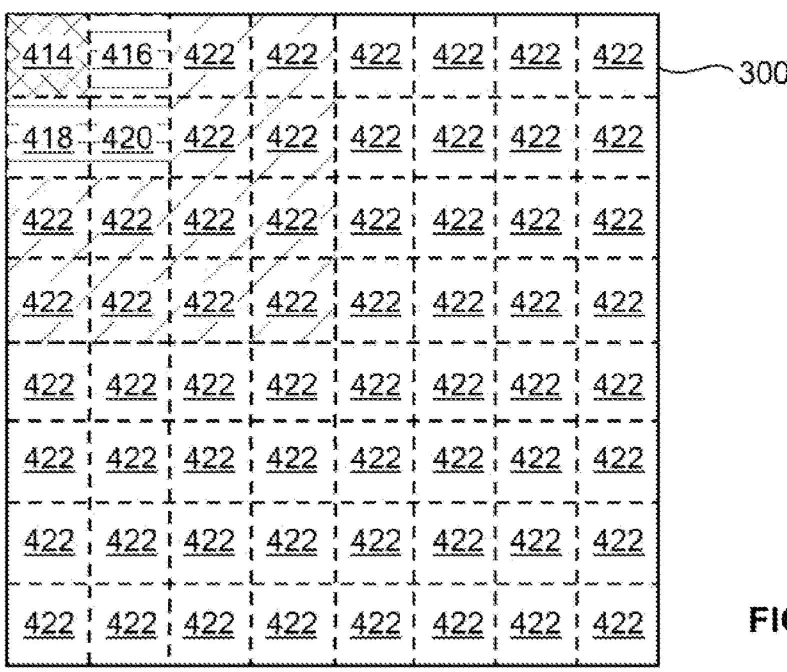

414
416
418
420
422
300

FIG. 6D

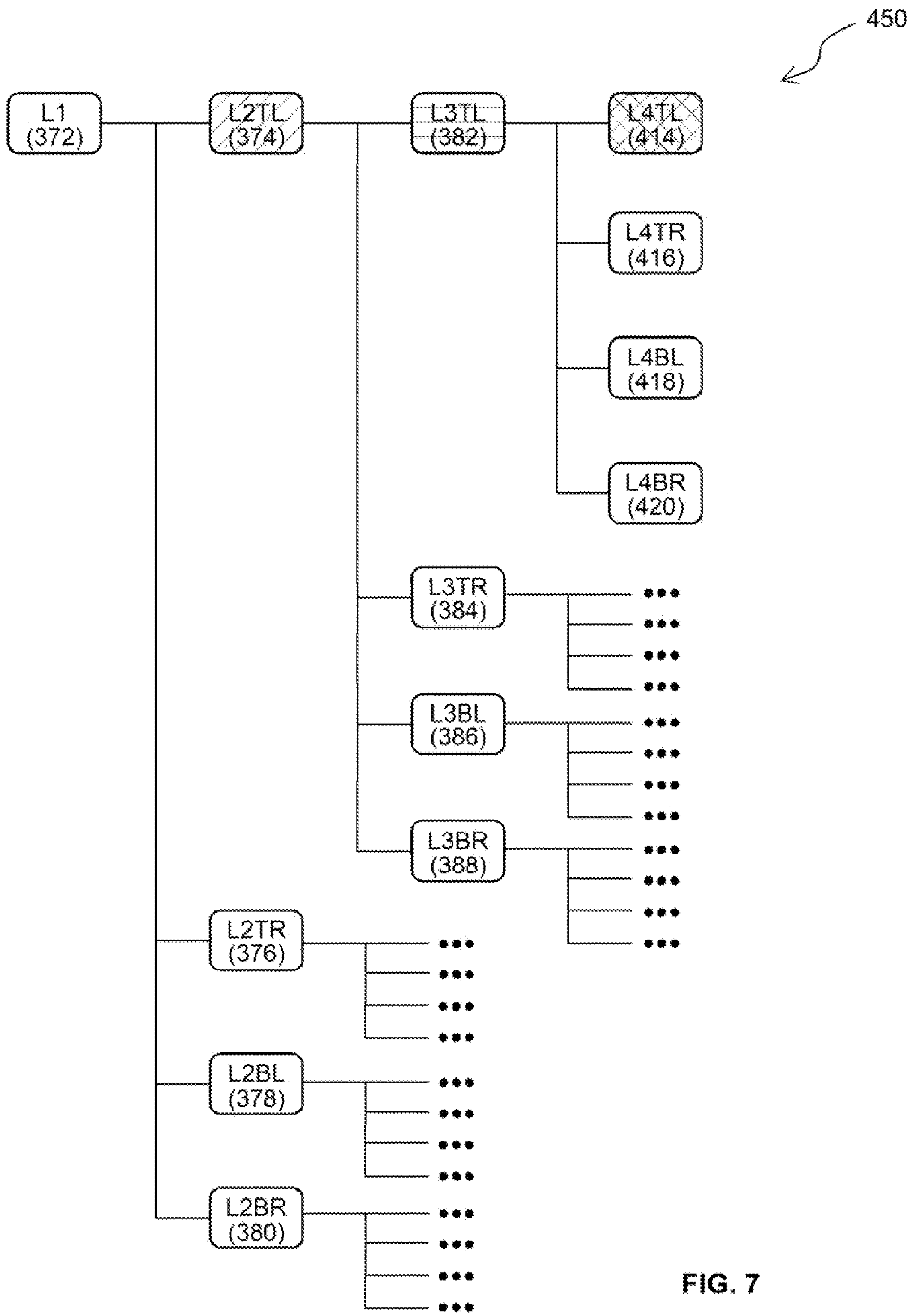

450
L1
(372)
L2TL
(374)
L3TL
(382)
L4TL
(414)
L4TR
(416)
L4BL
(418)
L4BR
(420)
L3TR
(384)
L3BL
(386)
L3BR
(388)
L2TR
(376)
L2BL
(378)
L2BR
(380)

FIG. 7

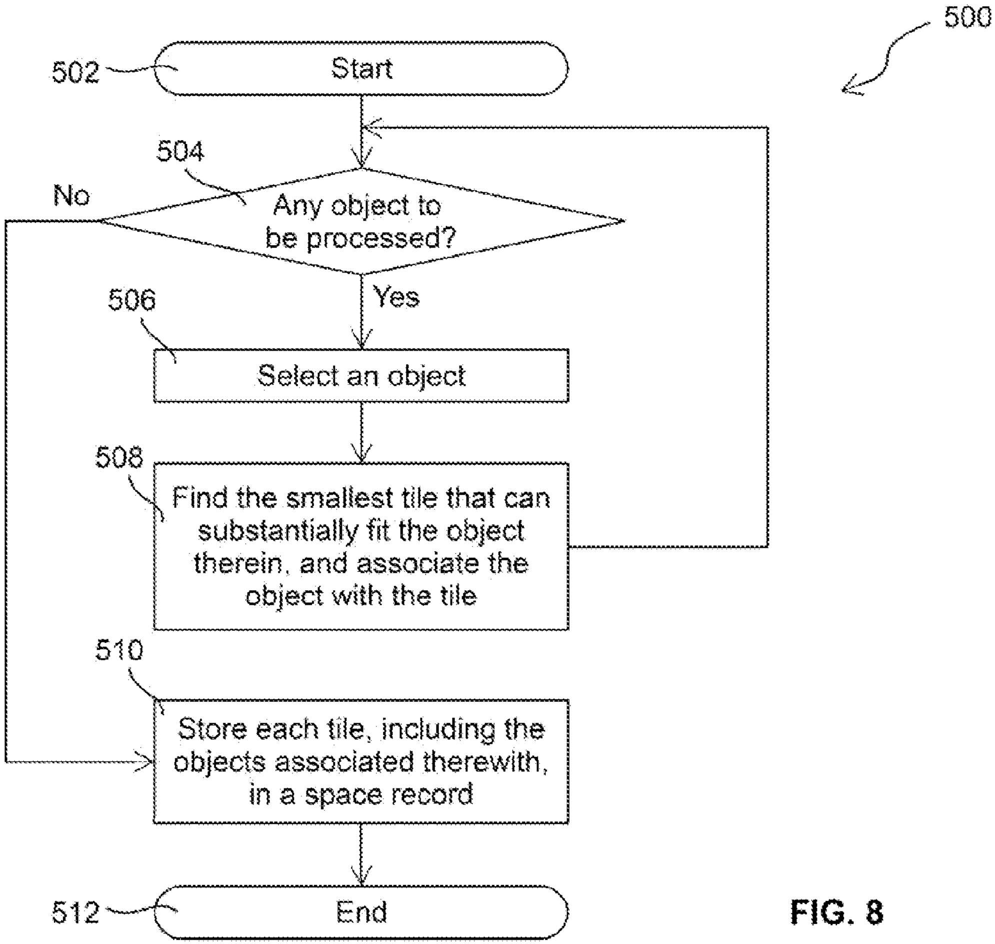

500
502
Start
504
No
Any object to be processed?
Yes
506
Select an object
508
Find the smallest tile that can substantially fit the object therein, and associate the object with the tile
510
Store each tile, including the objects associated therewith, in a space record
512
End

FIG. 8

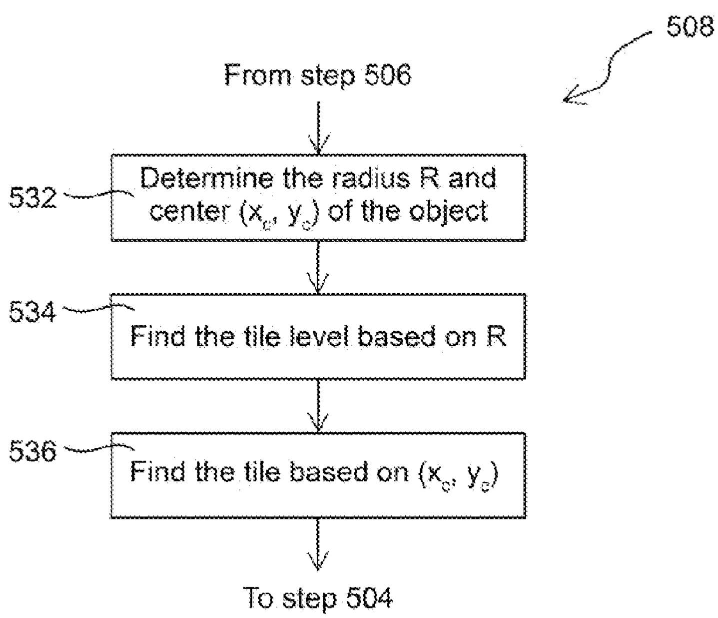

508
From step 506
532
Determine the radius R and center (x_c, y_c) of the object
534
Find the tile level based on R
536
Find the tile based on (x_c, y_c)
To step 504

FIG. 9

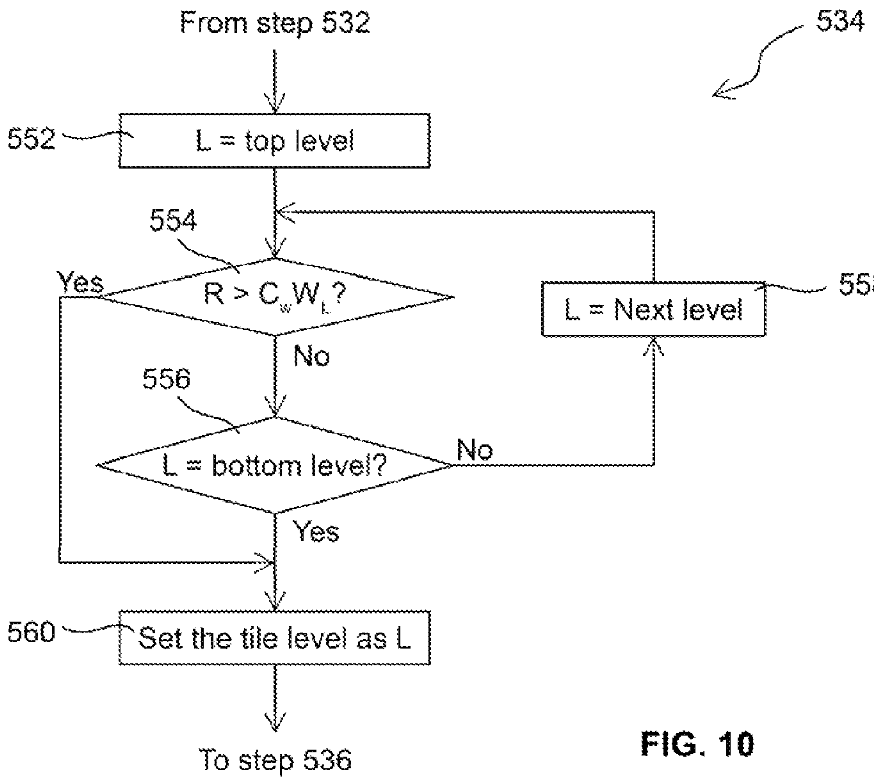


FIG. 10

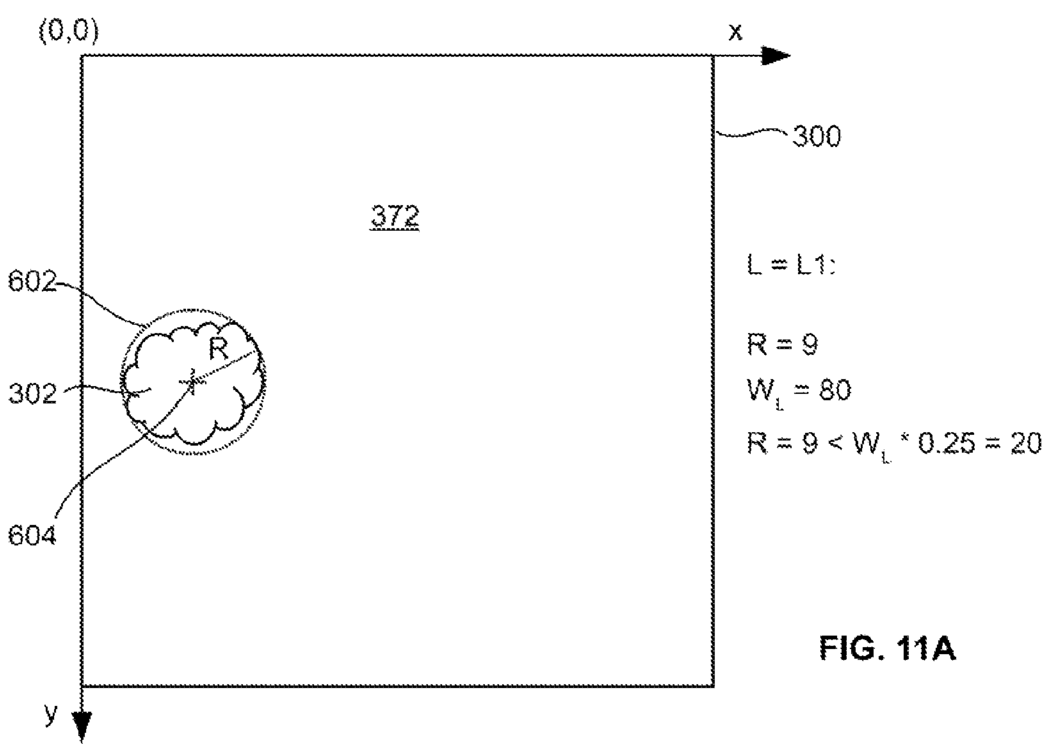


FIG. 11A

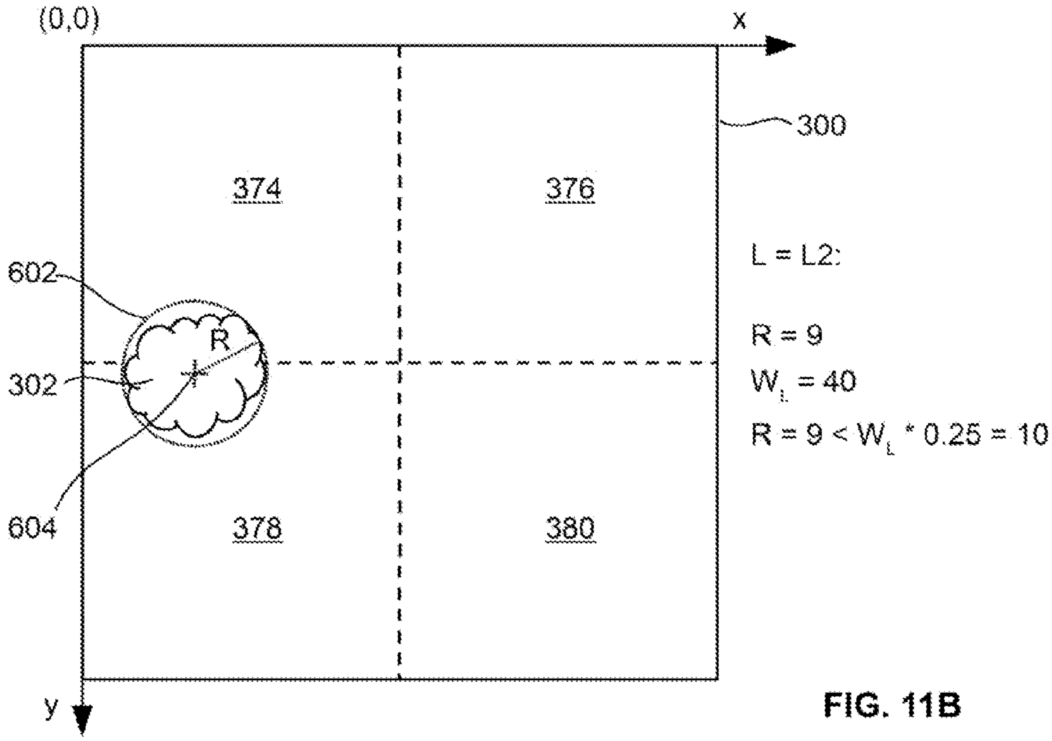


FIG. 11B

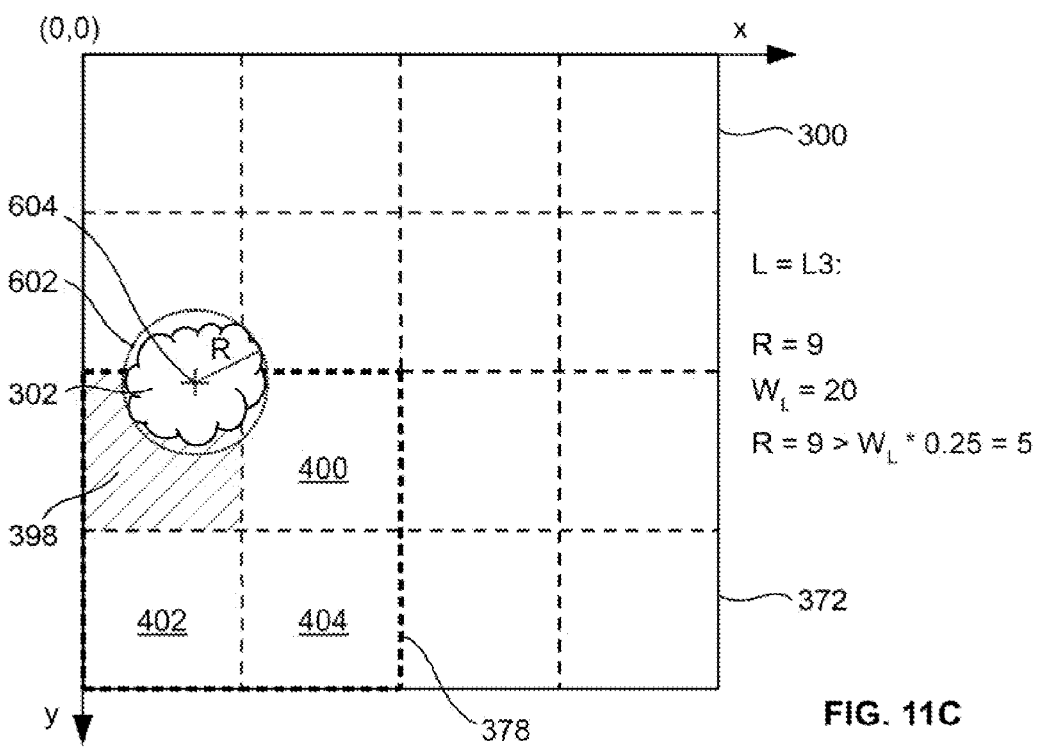


FIG. 11C

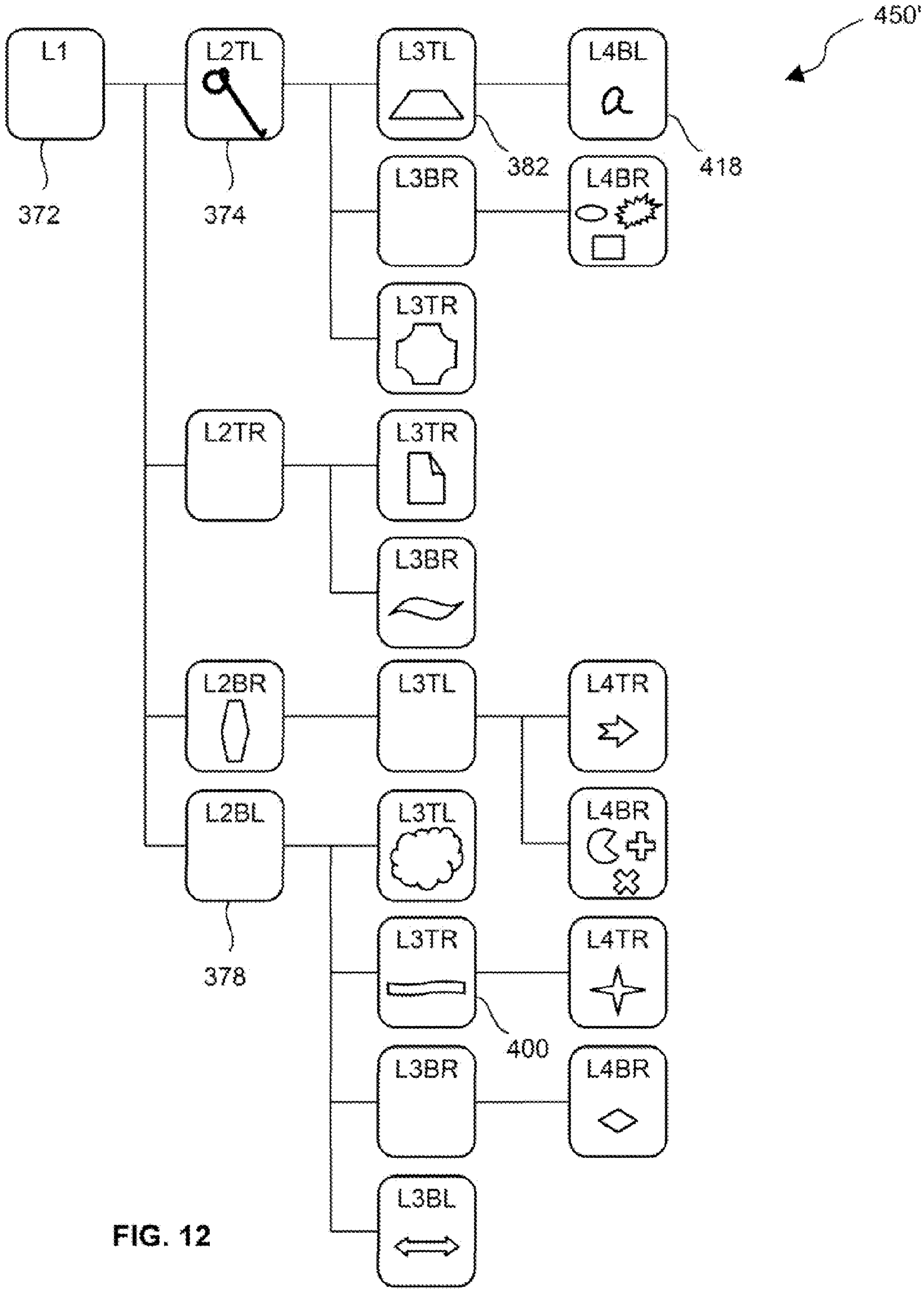

450'
L1
L2TL
L3TL
L4BL
a
372
374
382
418
L3BR
L4BR
L3TR
L2TR
L3TR
L3BR
L2BR
L3TL
L4TR
L2BL
L3TL
L4BR
378
L3TR
L4TR
400
L3BR
L4BR
L3BL

FIG. 12

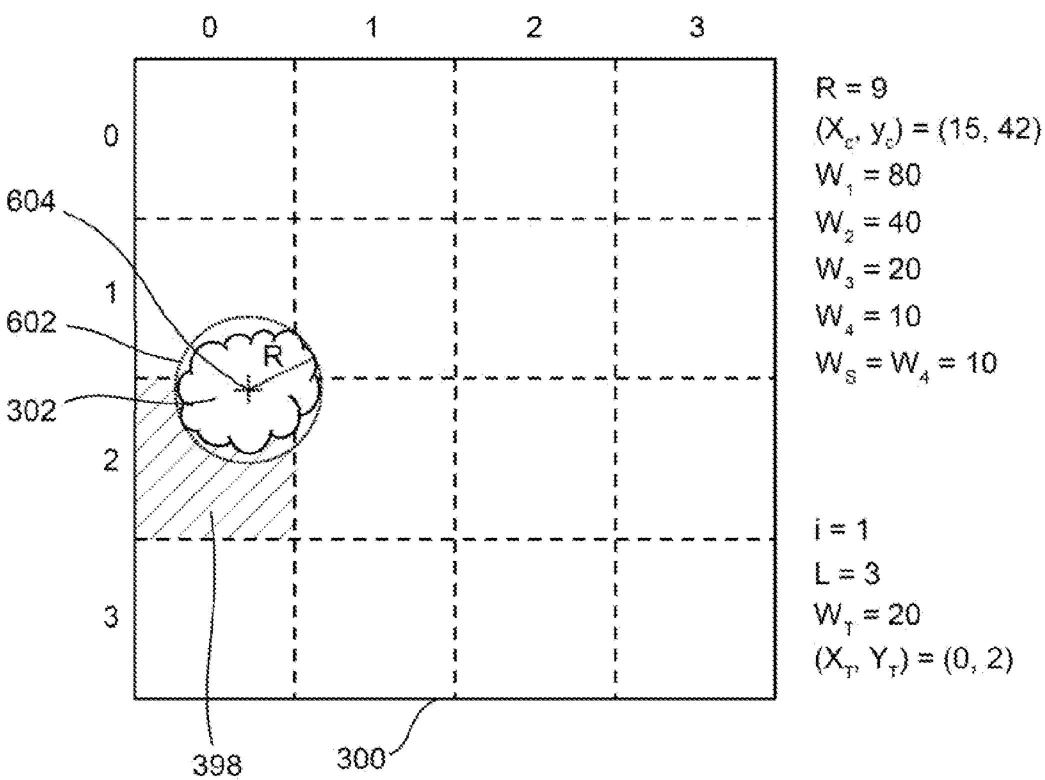
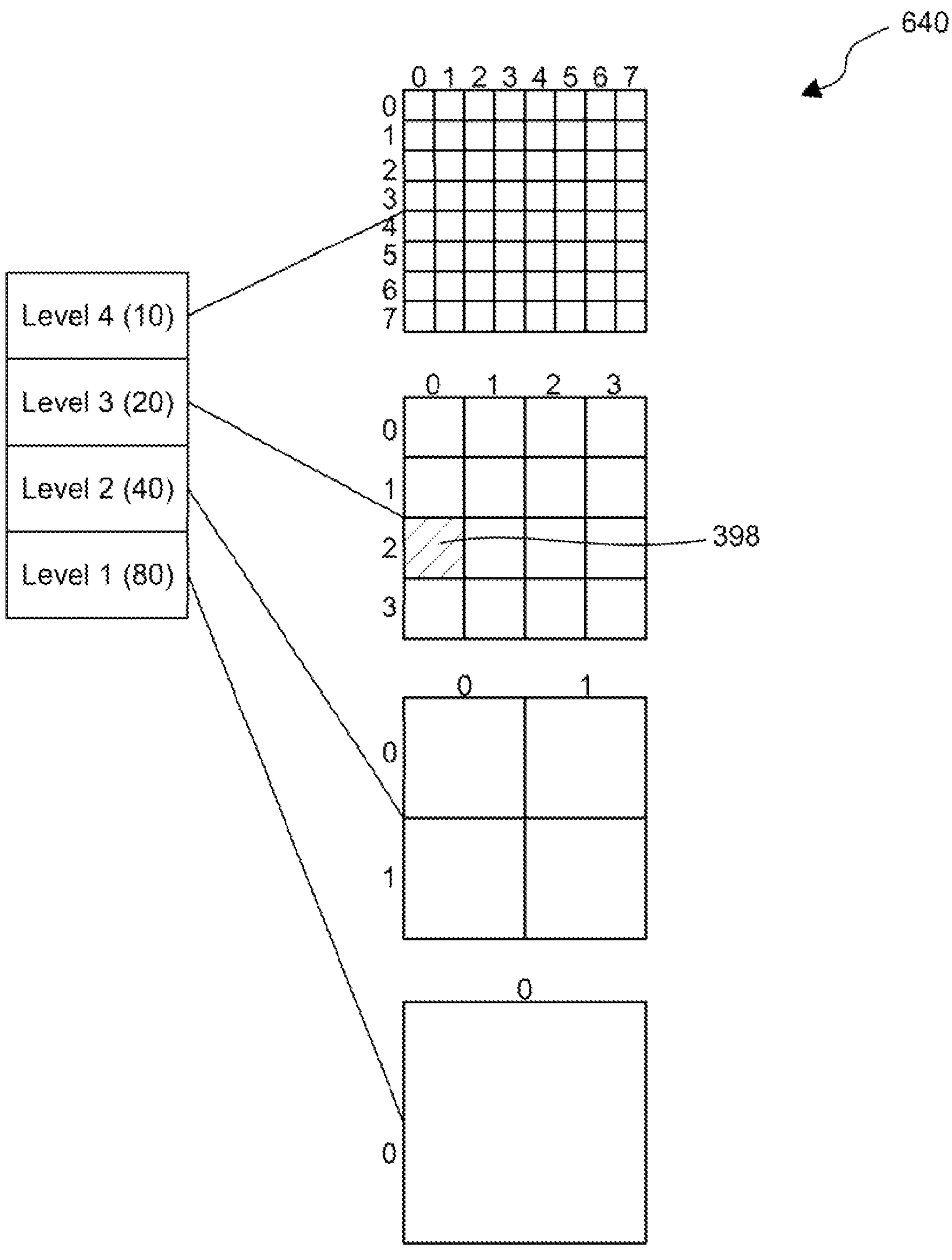

0
1
2
3
0
1
2
3
604
602
302
R
398
300
R = 9
$(X_c, y_c) = (15, 42)$
$W_1 = 80$
$W_2 = 40$
$W_3 = 20$
$W_4 = 10$
$W_S = W_4 = 10$
i = 1
L = 3
$W_T = 20$
$(X_T, Y_T) = (0, 2)$

FIG. 13



640
Level 4 (10)
Level 3 (20)
Level 2 (40)
Level 1 (80)
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7
0 1 2 3
0 1 2 3
398
0 1
0 1
0
0

FIG. 14

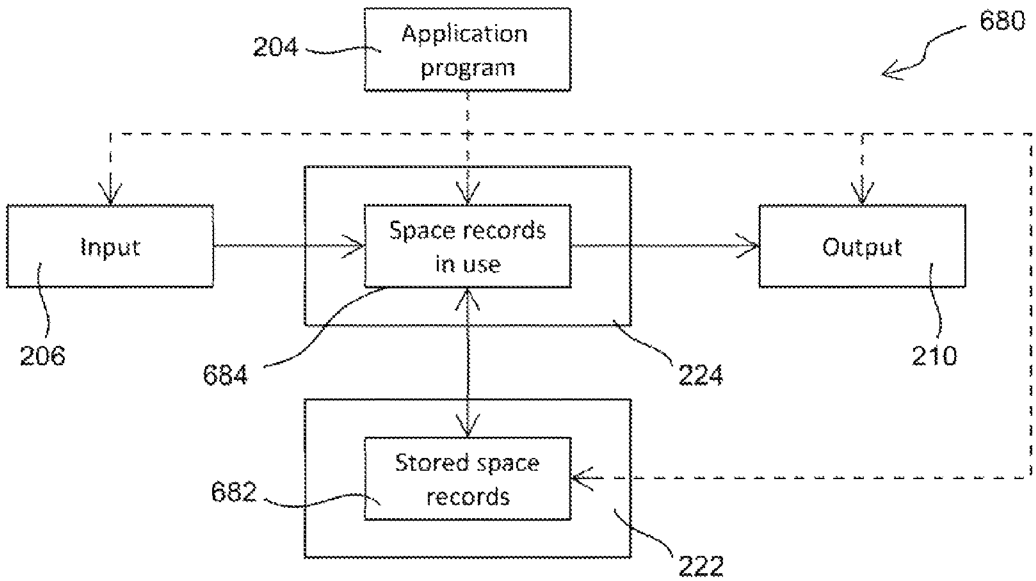

680
204
Application program
Input
206
Space records in use
684
224
Output
210
Stored space records
682
222

FIG. 15

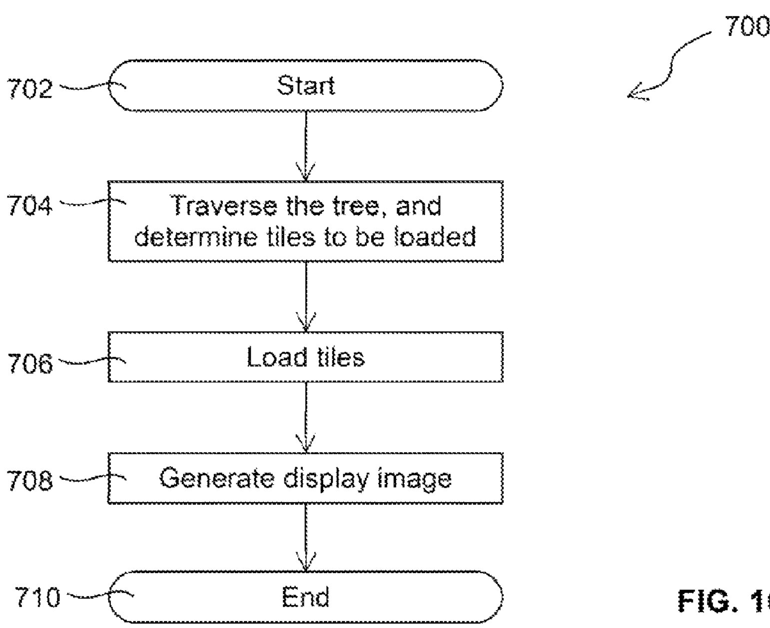
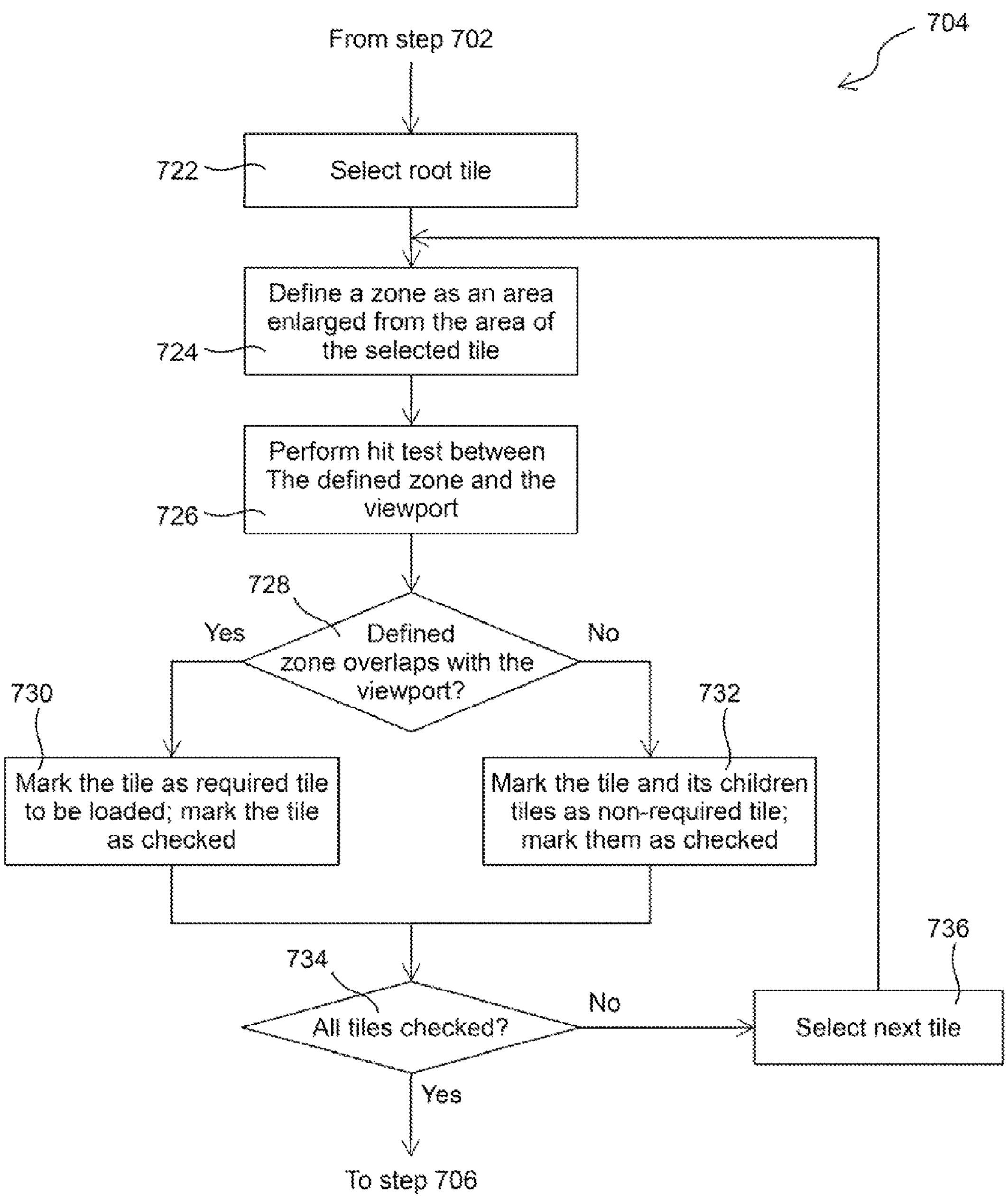

700
702
Start
704
Traverse the tree, and determine tiles to be loaded
706
Load tiles
708
Generate display image
710
End

FIG. 16



704
From step 702
722
Select root tile
724
Define a zone as an area enlarged from the area of the selected tile
726
Perform hit test between The defined zone and the viewport
728
Defined zone overlaps with the viewport?
Yes
No
730
Mark the tile as required tile to be loaded; mark the tile as checked
732
Mark the tile and its children tiles as non-required tile; mark them as checked
734
All tiles checked?
No
736
Select next tile
Yes
To step 706

FIG. 17

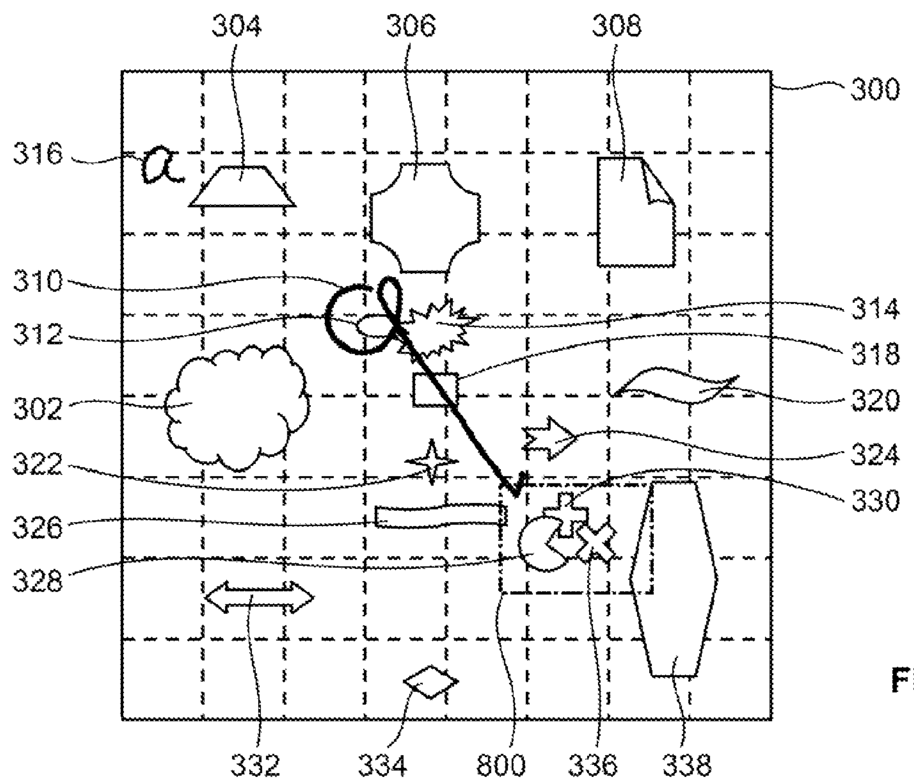


FIG. 18

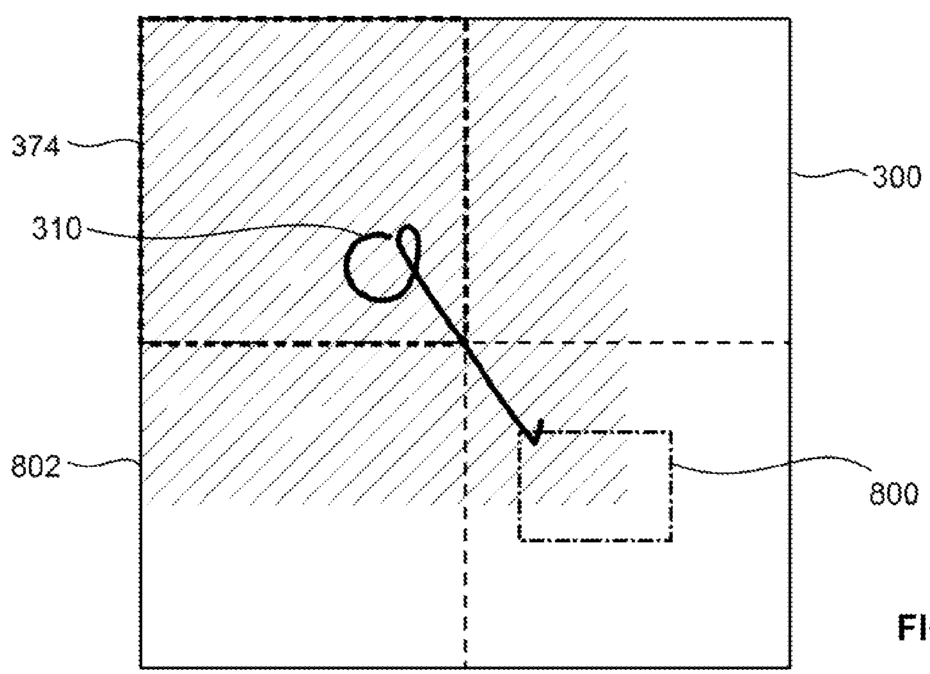


FIG. 19A

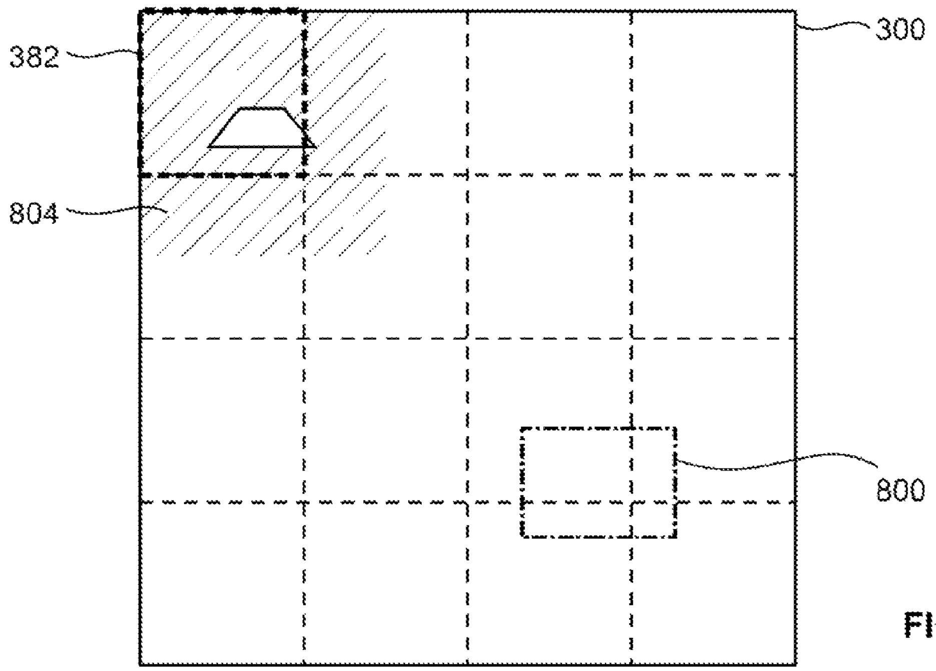


FIG. 19B

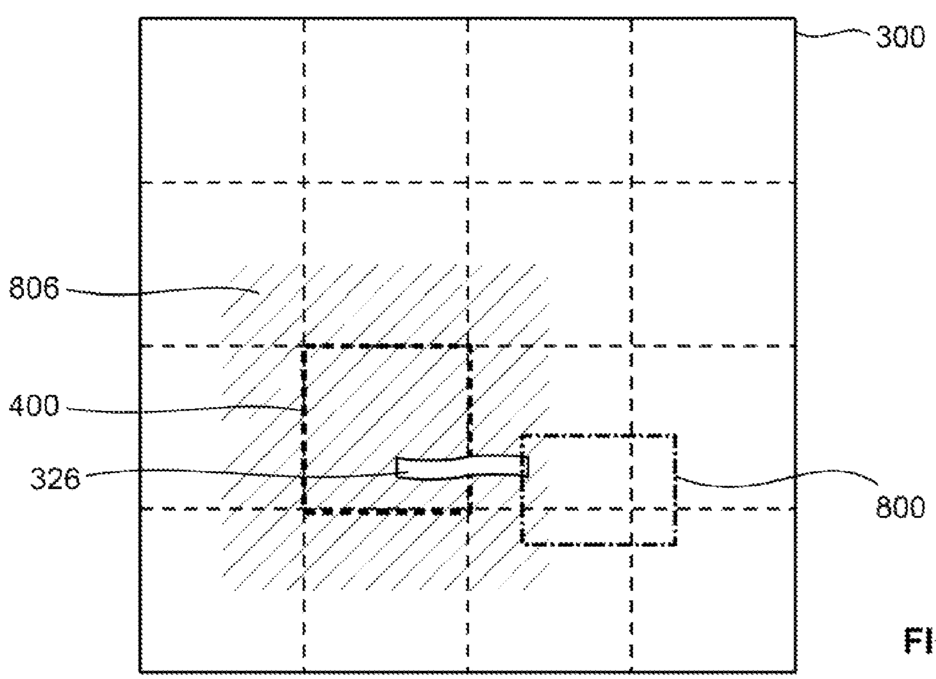


FIG. 19C

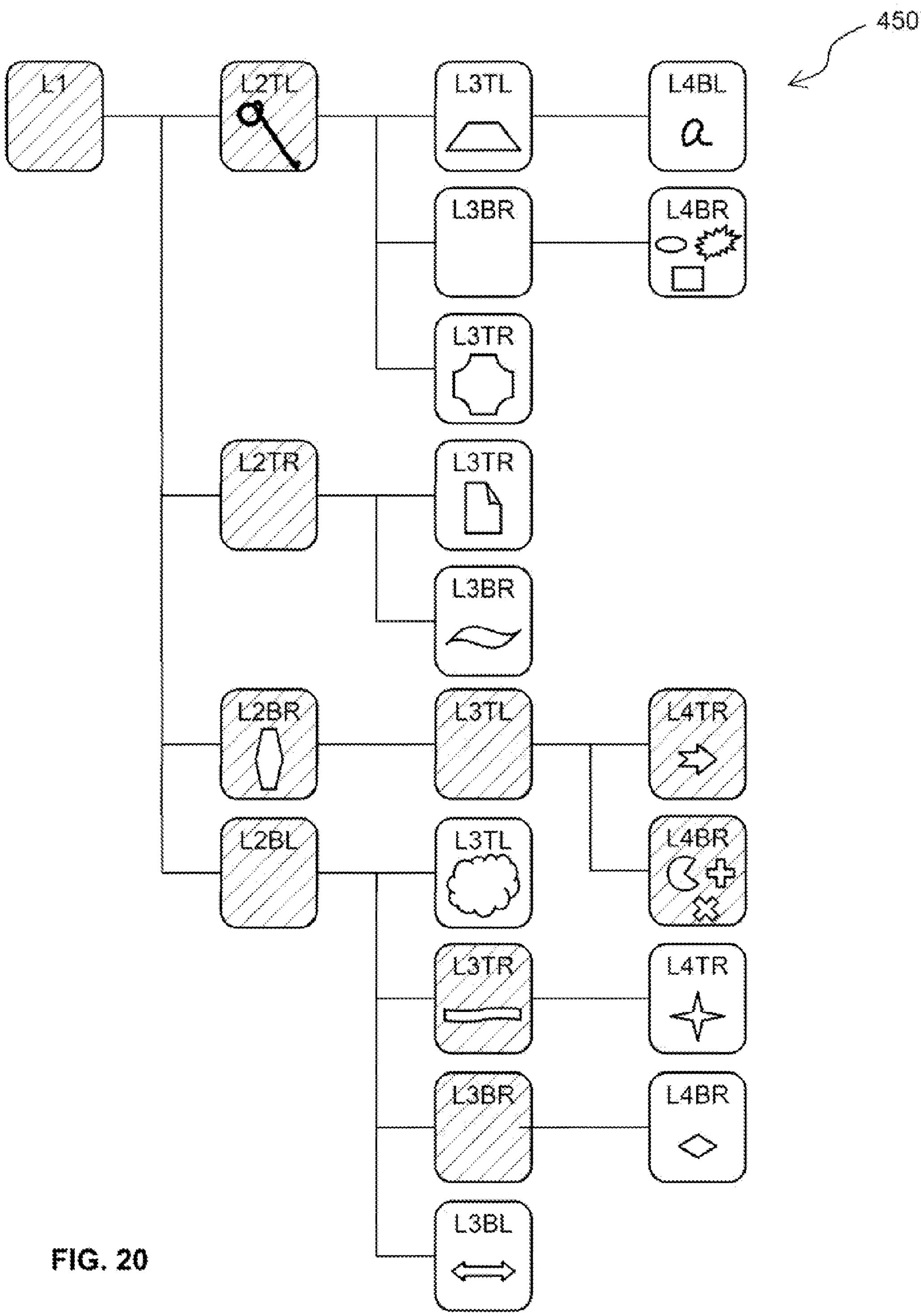

450'
L1
L2TL
L3TL
L4BL
a
L3BR
L4BR
L3TR
L2TR
L3TR
L3BR
L2BR
L3TL
L4TR
L2BL
L3TL
L4BR
L3TR
L4TR
L3BR
L4BR
L3BL

FIG. 20

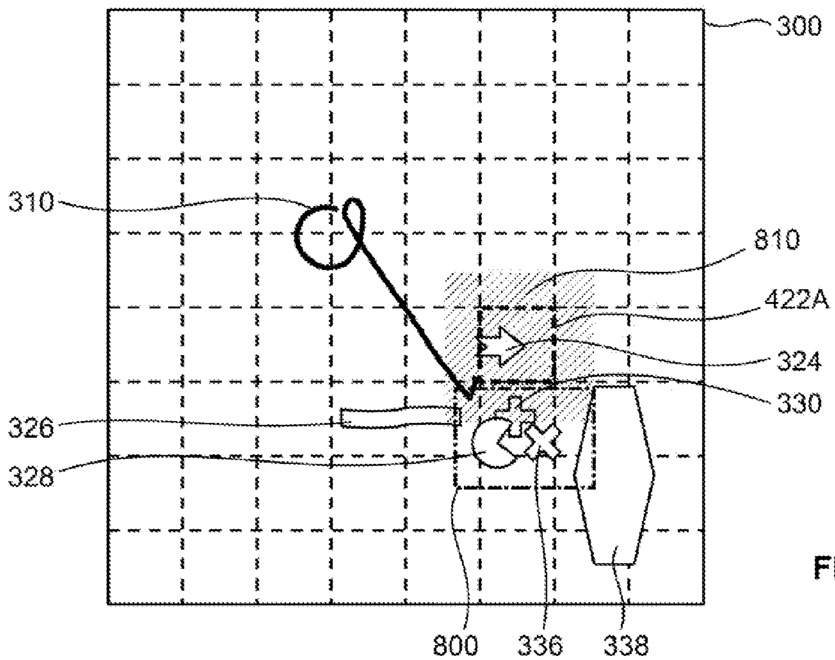


FIG. 21

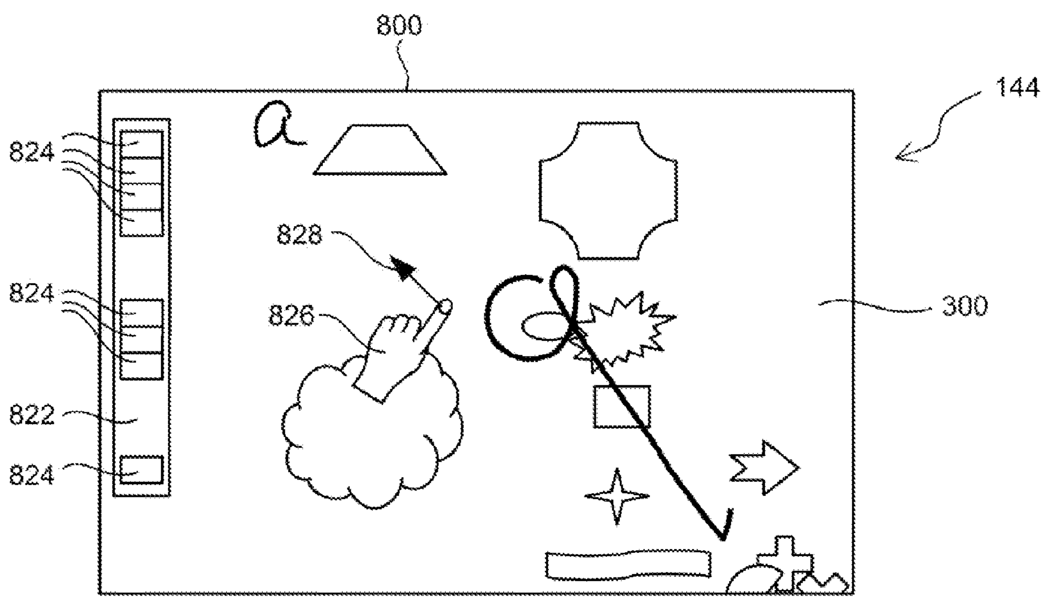


FIG. 22A

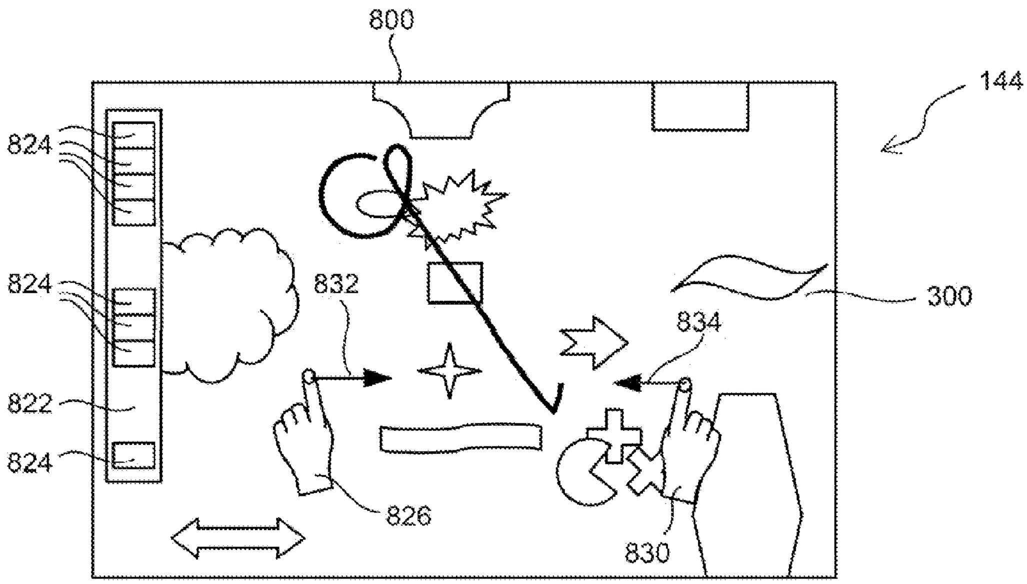


FIG. 22B

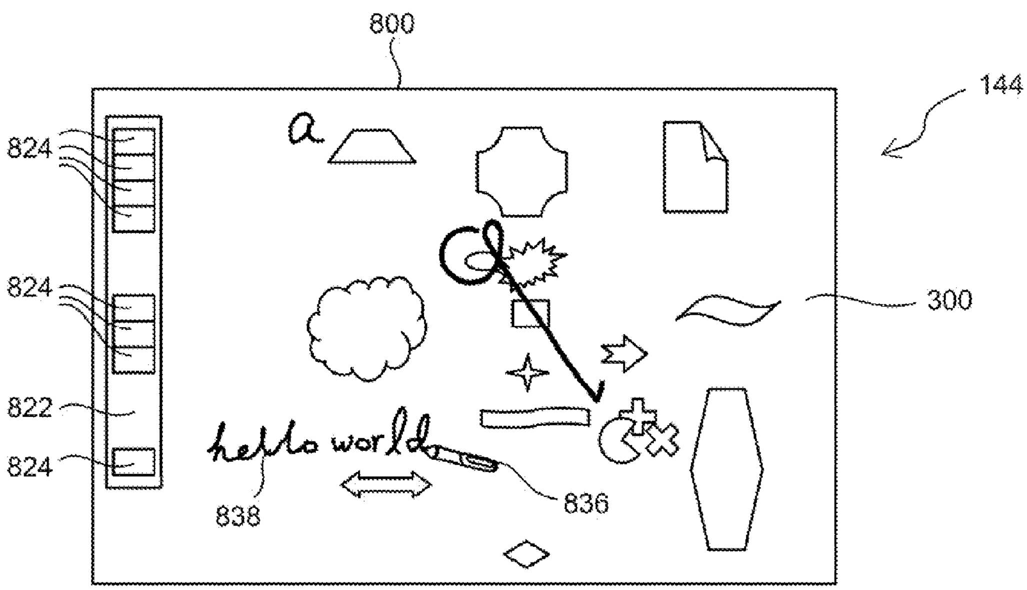


FIG. 22C

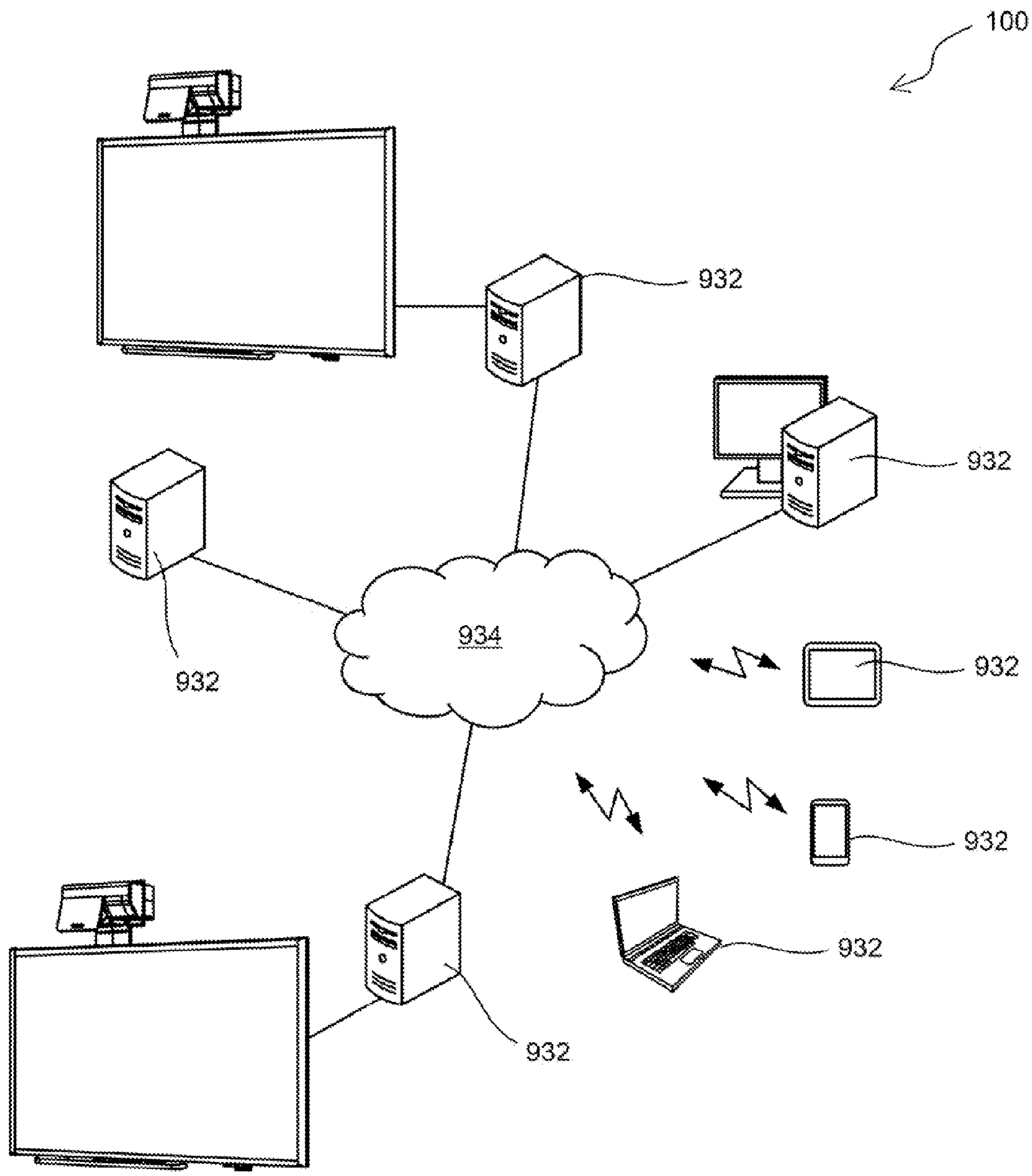


FIG. 23

METHOD FOR PARTITIONING, MANAGING AND DISPLAYING A COLLABORATION SPACE AND INTERACTIVE INPUT SYSTEM EMPLOYING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/971,617, filed Mar. 28, 2014, the entirety of which is incorporated herein by reference.

FIELD OF THE DISCLOSURE

The present invention relates generally to collaboration, and in particular to a method of partitioning, managing and displaying a collaboration space and an interactive input system employing same.

BACKGROUND

Interactive input systems are known, allowing users to inject input (e.g., digital ink, mouse events etc.) into an application program using an active pointer (e.g., a pointer that emits light, sound, or other signal), a passive pointer (e.g., a finger, cylinder or other suitable object) or other suitable input devices such as a mouse or trackball, are known. Such interactive input systems include but are not limited to: touch systems comprising touch panels employing analog resistive or machine vision technology to register pointer input such as those disclosed in U.S. Pat. Nos. 5,448,263; 6,141,000; 6,337,681; 6,747,636; 6,803,906; 7,232,986; 7,236,162; 7,274,356; and 7,532,206, all assigned to SMART Technologies ULC of Calgary, Alberta, Canada, assignee of the subject disclosure, the entire disclosures of which are incorporated herein by reference; touch systems comprising touch panels employing electromagnetic, capacitive, acoustic or other technologies to register pointer input; tablet; laptop computers; desktop computers; smartphones; personal digital assistants (PDAs) and other handheld devices; and other similar devices.

U.S. Pat. No. 6,803,906 to Morrison et al. discloses a touch system that employs machine vision to detect pointer interaction with a touch surface on which a computer-generated image is presented. A rectangular bezel or frame surrounds the touch surface and supports digital imaging devices at its corners. The digital imaging devices have overlapping fields of view that encompass and look generally across the touch surface. The digital imaging devices acquire images looking across the touch surface from different vantages and generate image data. Image data acquired by the digital imaging devices is processed by on-board digital signal processors to determine if a pointer exists in the captured image data. When it is determined that a pointer exists in the captured image data, the digital signal processors convey pointer characteristic data to a master controller, which in turn processes the pointer characteristic data to determine the location of the pointer in (x,y) coordinates relative to the touch surface using triangulation. The pointer coordinates are conveyed to a computer executing one or more application programs. The computer uses the pointer coordinates to update the computer-generated image that is presented on the touch surface. Pointer contacts on the touch surface can therefore be recorded as writing or drawing or used to control execution of application programs executed by the computer.

Multi-touch interactive input systems that receive and process input from multiple pointers using machine vision are also known. One such type of multi-touch interactive input system exploits the well-known optical phenomenon of frustrated total internal reflection (FTIR). According to the general principles of FTIR, light injected into an optical waveguide at an appropriate angle is completely reflected between the opposite surfaces of the waveguide (so called the total internal reflection (TIR) of light). When an object such as a pointer touches the waveguide surface, the index of refraction of the media adjacent the waveguide about the touch point is changed (due to the media changing from air to the pointer). Consequently, the TIR of light is frustrated at the touch point, causing some light to escape from the touch point. In such a multi-touch interactive input system, the machine vision system captures images including the point(s) of escaped light, and processes the images to identify the touch position(s) on the waveguide surface based on the point(s) of escaped light for use as input(s) to application programs.

Interactive input systems may be used by a single user or a plurality of users to collaboratively work thereon. For example, an interactive input system may provide a collaboration space such as a digital canvas for users to inject thereon various graphic objects such as digital ink, lines, shapes, images, text, animation, graphic representations of sounds and other types of multimedia content, and the like. A user may adjust the display of the interactive input system to different zoom levels as desired to improve readability or comprehension of the information.

Zoomable user interfaces have been considered. For example, Internet-based "online" map applications such as Google Maps™ offered by Google Inc. of Mountain View, Calif., USA, provide zoomable user interfaces to allow users to adjust the displayed maps to various levels of detail as desired.

U.S. Patent Publication No. 2013/0198653 assigned to SMART Technologies ULC of Calgary, Alberta, Canada, assignee of the subject disclosure, the content of which is incorporated herein by reference in its entirety, discloses a method of displaying input during a collaboration session, comprising providing a canvas for receiving input from at least one participant using a computing device joined to the collaboration session; and displaying the canvas at one of a plurality of discrete zoom levels on a display associated with the computing device.

A collaboration space may comprise a large number of graphic objects. Managing and displaying the graphic objects may then impose a significant computational cost to the interactive system.

One solution for reducing the computational cost of managing and displaying graphic objects in a collaboration space is to partition the collaboration space into a plurality of fixed-size blocks or "tiles", and associate graphic objects with respective tiles based on the locations of the graphic objects. The content of each tile, including the graphic objects associated therewith, is stored separately, e.g., as a file.

For example, as shown in FIG. **1**, a collaboration space **10** is partitioned in a known manner to a plurality of fixed-size, square tiles, each of which is associated with graphic objects whose geometry centers fall within. The content of each tile, including the graphic objects associated therewith, is stored as a file. For example, graphic object **16** is associated with tile **12** and stored in a first file, and graphic objects **18** to **28** are associated with tile **14** and stored in a second file.

When displaying the collaboration space, tiles comprising graphic objects that overlap with the viewport such as the display or a portion thereof, are determined and loaded to the memory of the interactive input system for rendering and display.

In the example of FIG. **1**, a user (not shown) has zoomed-in the display of the collaboration space **10** such that the viewport **30** is to display a portion of the tile **12**. The content of tile **12**, including graphic object **16**, is then loaded to the memory of the system for rendering and display. As graphic object **18** overlaps with the viewport **30**, its associated tile, i.e., tile **14**, is also loaded to the memory of the system for rendering and display. As a result, all graphic objects **18** to **28** associated with tile **14** are loaded. However, as graphic objects **20** to **28** do not overlap with the viewport **30**, loading and processing them causes unnecessary computational cost to the system.

It is therefore an object to provide a novel method of partitioning, managing and displaying a collaboration space and an interactive input system employing the same.

SUMMARY

According to one aspect of this disclosure, there is provided a computerized method of managing a collaboration space having one or more graphic objects therein, the method comprising: partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at a level either being a leaf node or being subdivided into a plurality of smaller tiles at the next level; and for each graphic object, determining an object tile in said tree structure for said graphic object; said object tile being the smallest tile in the tree structure that accommodates at least a predefined major portion of said graphic object; and associating said graphic object with the determined object tile.

In some embodiments, each tile at the same level has the same size.

In some embodiments, the tree structure may be a Quad-Tree, in which each tile at a level either is a leaf node or is subdivided into four smaller tiles at the next level.

In some embodiments, the object tile is the smallest tile in the tree structure that accommodates the entirety of said graphic object.

In some embodiments, determining an object tile in said tree structure for said graphic object further comprises: determining a tile level L in the tree structure such that the size of each tile at said tile level L is larger than that of at least a predefined portion of said graphic object; and determining the object tile as a tile at said tile level that overlaps with at least the predefined major portion of said graphic object. Hereinafter, the term “size” refers to areal size.

To determine the tile level L, in some embodiments, a comparison can be made between a tile at a tile level and the graphic object to determine if the tile size is larger than that of at least a predefined major portion of the graphic object. In some alternative embodiments, a comparison can be made between a tile at a tile level and a bounding region of the graphic object to determine if the tile size is larger than that of at least a predefined major portion of the bounding region of the graphic object. Here, a bounding region is a shape enclosing the graphic object. Generally, such a bounding region has a simplified profile for simplifying calculation. Depending on the implementation, the bounding region may be a circle, a rectangle, an oval or other suitable shapes.

For example, in some embodiments, the tile level L is determined as the tile level of the smallest tile that the width thereof is larger than or equal to the diameter of a bounding circle of the graphic object weighted by a weighting factor C_d. The tile in the tile level L for said graphic object is determined by determining a tile in the tile level L that overlaps with the center of a bounding circle of said graphic object.

In some embodiments, the first weighting factor C_d is one (1).

In some embodiments, the tiles are square tiles, and the tile level L is determined by iterating through the tree structure from the level having largest tile width to the level having the smallest tile width, to determine the tile level L having the largest tile width W_L that satisfies $R>C_wW_L$, where R is the radius of the bounding circle of the graphic object, C_w is a weighting factor, and $C_d=1/(4C_w)$. In some embodiments, the weighting factor C_w is 0.25.

In some embodiments, the tile level L is determined without iterating through the tree structure, by first calculating a suitable tile level L_T and then calculates the index of the tile at level L_T for associating with the graphic object.

In some embodiments, at least the object tiles, i.e., tiles that have at least one graphic object associated therewith, are stored in a first memory area, wherein each object tile is stored therein as a separate record that may be independently accessed. In some embodiments, the first memory area may be memory for long-term storage of data, such as hard drive(s), solid-state drives, flash drives, or the like. In some other embodiments, the first memory area may be a cache memory area.

In some embodiments, the linkages of the object tiles are also stored.

In some embodiments, the empty-but-intermediate tiles that have no graphic object associated therewith but are linked intermediate between a root tile and an object tile, are also stored in the first memory area.

In some embodiments, the above computerized method further comprises: determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space; determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and loading the determined set of tiles from the first memory area to a second memory area.

In some embodiments, the second memory area may be the memory area for temporarily storing data used during the collaboration, e.g., a Random Access Memory (RAM) area. The second memory area may be local to the first memory area, e.g., both physically integrated in the same computing device. The first and second memory areas may be different storage media and/or managed by different function modules or controllers of the computing device. Alternatively, the first and second memory areas may be the same storage media managed by the same function module or controller of the computing device. In other words, the first and second memory areas may be two portions of the same storage.

In some alternative embodiments, the second memory area may be remote to the first memory area, e.g., the second memory area being physically integrated in a computing device while the first memory area being a removable hard drive functionally connected to the computing device.

In some other embodiments, the second memory area may be a memory area on another computing device, and therefore is remote to the first memory area. In these embodiments, a first computing device stores the collaboration space and the graphic objects therein in a first memory area as described above, wherein the first area is in the first computing device. Under the request of a second computing device, the first computing device loads a set of tiles determined as described above to a second memory area in the second computing device via a wired or wireless communication channel.

In some embodiments, the aforementioned determination of a set of tiles comprises: for each tile in the tree structure: defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor C_b; determining if the view port overlaps with said zone; and marking the tile as a required tile of said set of tiles if the view port overlaps with said zone. In some embodiments, the weighting factor C_b is 2.

According to another aspect of this disclosure, there is provided an interactive input system for managing a collaboration space having one or more graphic objects, comprising: a processing structure; a memory functionally coupled to said processing structure and storing at least a portion of said collaboration space; wherein said processing structure executes computer-executable code for: partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at a level either being a leaf node or being subdivided into a plurality of smaller tiles at the next level; and associating each graphic object with an object tile in said tree structure, said object tile being the smallest tile in the tree structure that accommodates at least a predefined major portion of said graphic object.

In some embodiments, each tile at the same level having the same size.

In some embodiments, the tree structure may be a Quad-Tree, in which each tile at a level either is a leaf node or is subdivided into four (4) smaller tiles at the next level.

In some embodiments, said object tile is the smallest tile in the tree structure that accommodates the entirety of said graphic object.

In some embodiments, said computer-executable code for associating each graphic object with an object tile in said tree structure further comprises computer-executable code for: for each graphic object, determining a tile level L in the tree structure such that the size of each tile at said level L is larger than that of at least the predefined major portion of said graphic object; determining an object tile at said tile level L that overlaps with at least the predefined major portion of said graphic object; and associating said graphic object with said object tile.

In some embodiments, said tile level L is determined as the tile level of the smallest tile that the width thereof is larger than or equal to the diameter of a bounding circle of the graphic object weighted by a weighting factor C_d.

In some embodiments, said tiles are square tiles, and said computer-executable code for determining a tile level L comprises computer-executable code for: iterating from the level having largest tile width to the level having the smallest tile width, to determine the tile level L having the largest tile width W_L that satisfies $R>C_wW_L$, where R is the radius of the bounding circle of the graphic object, C_w is a weighting factor, and $C_d=1/(4C_w)$.

In some embodiments, said weighting factor C_w is 0.25.

In some embodiments, said computer-executable code for determining an object tile in said tile level that overlaps with at least the major portion of said graphic object comprises computer-executable code for: determining an object tile in said tile level that overlaps with the center of a bounding circle of said graphic object.

In some embodiments, the processing structure of the aforementioned interactive input system further executes computer-executable code for: storing, in a first memory area, at least the object tiles, wherein each object tile is stored therein as a separate record that may be independently accessed.

In some embodiments, said processing structure further executes computer-executable code for: storing, in said first memory area, the linkages of the object tiles.

In some embodiments, said processing structure further executes computer-executable code for: storing, in said first memory area, the empty-but-intermediate tiles that have no graphic object associated therewith but are linked intermediate between a root tile and an object tile.

In some embodiments, the processing structure of the aforementioned interactive input system further executes computer-executable code for: determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space; determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and loading the determined set of tiles from the first memory area to a second memory area.

In some embodiments, said first memory area is local to said second memory area.

In some embodiments, said first memory area is remote to said second memory area.

In some embodiments, the computer-executable code for determining a set of tiles comprises computer-executable code for: for each tile in the tree structure: defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor C_b; determining if the view port overlaps with said zone; and marking the tile as a required tile of said set of tiles if the view port overlaps with said zone. In some embodiments, the weighting factor C_b is 2.

According to another aspect of this disclosure, there is provided a computer-readable storage device comprising computer-executable instructions for managing a collaboration space having one or more graphic objects, wherein the instructions, when executed, cause a processor to perform actions comprising: partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at a level either being a leaf node or being subdivided into a plurality of smaller tiles at the next level; and associating each graphic object with an object tile in said tree structure; said object tile being the smallest tile in the tree structure that substantially accommodate said graphic object.

In some embodiments, each tile at the same level having the same size.

In some embodiments, the tree structure may be a Quad-Tree, in which each tile at a level either is a leaf node or is subdivided into four (4) smaller tiles at the next level.

In some embodiments, said object tile is the smallest tile in the tree structure that accommodates the entirety of said graphic object.

In some embodiments, associating each graphic object with an object tile in said tree structure further comprises: for each graphic object, determining a tile level L in the tree structure such that the size of each tile at said level L is larger than that of at least a predefined major portion of said graphic object; determining an object tile at said tile level L that overlaps with at least the predefined major portion of said graphic object; and associating said graphic object with said object tile.

In some embodiments, said tile level L is determined as the tile level of the smallest tile that the width thereof is larger than or equal to the diameter of a bounding circle of the graphic object weighted by a weighting factor C_d.

In some embodiments, said tiles are square tiles, and determining a tile level L comprises: iterating from the level having largest tile width to the level having the smallest tile width, to determine the tile level L having the largest tile width W_L that satisfies $R>C_wW_L$, where R is the radius of the bounding circle of the graphic object, C_w is a weighting factor, and $C_d=1/(4C_w)$.

In some embodiments, said weighting factor C_w is 0.25.

In some embodiments, determining an object tile at said tile level that overlaps with at least the predefined major portion of said graphic object comprises: determining the object tile as a tile at said tile level that overlaps with at least the predefined major portion of said graphic object.

In some embodiments, the instructions, when executed, further cause the processor to perform actions comprising: storing, in a first memory area, at least the object tiles, wherein each object tile is stored therein as a separate record that may be independently accessed.

In some embodiments, said instructions, when executed, further cause the processor to perform actions comprising: storing, in said first memory area, the linkages of object tiles.

In some embodiments, said instructions, when executed, further cause the processor to perform actions comprising: storing, in said first memory area, the empty-but-intermediate tiles that have no graphic object associated therewith but are linked intermediate between a root tile and an object tile.

In some embodiments, the instructions, when executed, further cause the processor to perform actions comprising: determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space; determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and loading the determined set of tiles from the first memory area to a second memory area.

In some embodiments, said first memory area is local to said second memory area.

In some embodiments, said first memory area is remote to said second memory area.

In some embodiments, the instructions, when executed, further cause the processor to perform actions comprising: for each tile in the tree structure: defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor C_b; determining if the view port overlaps with said zone; and marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

In some embodiments, the weighting factor C_b is 2.

According to another aspect of this disclosure, there is provided a method of controlling one or more memory devices for storing a collaboration space, said collaboration space having one or more graphic objects therein, the method comprising: partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at a level either being a leaf node or being subdivided into a plurality of smaller tiles in the next level; associating each graphic object with an object tile in said tree structure, said object tile being the smallest tile in the tree structure that substantially accommodates said graphic object; and storing at least the object tiles in said memory device, wherein each object tile is stored in at least one of said memory devices as a separate record that may be independently accessed.

In some embodiments, each tile at the same level having the same size.

In some embodiments, the tree structure may be a Quad-Tree, in which each tile at a level either is a leaf node or is subdivided into four (4) smaller tiles at the next level.

In some embodiments, the method further comprising: for each graphic object: determining a tile level L in the tree structure such that the size of each tile at said level L is larger than that of at least a predefined major portion of said graphic object; and determining the object tile as a tile at said tile level that overlaps with at least the predefined major portion of said graphic object.

In some embodiments, said tile level L is determined as the tile level of the smallest tiles that the width thereof is larger than or equal to the diameter of a bounding circle of the graphic object, weighted by a weighting factor C_d.

In some embodiments, said tiles are square tiles, and said determining a tile level L comprises: iterating from the level having largest tile width to the level having the smallest tile width, to determine the tile level L having the largest tile width W_L that satisfies $R>C_wW_L$, where R is the radius of the bounding circle of the graphic object, C_w is a weighting factor, and $C_d=1/(4C_w)$.

In some embodiments, said weighting factor C_w is 0.25.

In some embodiments, determining an object tile at said tile level that overlaps with at least the predefined major portion of said graphic object comprises: determining the object tile as a tile at said tile level that overlaps with the center of a bounding circle of said graphic object.

In some embodiments, the aforementioned method of controlling a memory device further comprising: storing, in said memory device, the linkages of object tiles.

In some embodiments, the aforementioned method of controlling a memory device further comprising: storing, in said first memory area, the empty-but-intermediate tiles that have no graphic object associated therewith but are linked intermediate between a root tile and an object tile.

In some embodiments, the aforementioned method of controlling a memory device further comprises: determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space; determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and reading out the determined set of tiles from said memory device.

In some embodiments, said viewport is local to said memory device.

In some embodiments, said viewport is remote to said memory device.

In some embodiments, determining a set of tiles comprises: for each tile in the tree structure: defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor C_b; determining if the view port overlaps with said zone; and marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

In some embodiments, the weighting factor C_b is 2.

According to another aspect of this disclosure, there is provided a method of controlling a memory device to read out at least a portion of data stored therein for generating an image to be displayed on a view port, said data being stored in said memory device as independently accessible records, each record representing a tile of a collaboration space having one or more graphic objects, said collaboration space being partitioned into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at a level either being a leaf node or being subdivided into a plurality of smaller tiles in the next level, and each graphic object in said collaboration space being associated with an object tile in said tree structure that is the smallest tile in the tree structure that substantially accommodates said graphic object, said method comprising: obtaining the linkages of the tree structure; determining the position of the viewport, said viewport displaying a display image of at least a portion of said collaboration space; determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and reading out, from said memory device, the records representing the determined set of tiles; wherein determining a set of tiles comprises: for each tile in the tree structure: defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor C_b; determining if the view port overlaps with said zone; and marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

In some embodiments, each tile at the same level having the same size.

In some embodiments, each tile at a level either is a leaf node or is subdivided into four smaller tiles at the next level.

In some embodiments, said second weighting factor C_b is 2.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the partitioning of a collaboration space, in accordance with a known method;

FIG. **2** is a simplified block diagram of the hardware structure of an interactive input system, according to an embodiment of the present disclosure;

FIG. **3** is a perspective view of an example of the interactive input system of FIG. **2**;

FIG. **4** is a simplified block diagram of the software architecture of the interactive input system of FIG. **2**.

FIG. **5** illustrates an example of a collaboration space having graphic objects therein, managed by the interactive input system of FIG. **2**;

FIGS. **6**A to **6**D show the partitioning of the collaboration space of FIG. **6** into a Quad-Tree structure, performed by the interactive input system of FIG. **2**;

FIG. **7** illustrates the Quad-Tree structure of the partitioned collaboration space of FIG. **5**;

FIGS. **8** to **10** illustrate a flowchart showing steps of associating graphic objects to tiles in the Quad-Tree structure of the partitioned collaboration space, performed by the interactive input system of FIG. **2**;

FIGS. **11**A to **11**C show an example of determining a tile in the Quad-Tree structure for associating with a graphic object, performed by the interactive input system of FIG. **2**;

FIG. **12** illustrates the Quad-Tree structure of the partitioned collaboration space of FIG. **6** after the graphic objects in the collaboration space are associated with tiles in the Quad-Tree structure;

FIG. **13** shows an example of directly determining a tile in the Quad-Tree structure for associating with a graphic object, according to an alternative embodiment;

FIG. **14** illustrates the data structure of the partitioned collaboration space, according to an alternative embodiment;

FIG. **15** is a simplified block diagram showing a software structure of the interactive input system of FIG. **2** during a collaboration session;

FIGS. **16** and **17** illustrate a flowchart showing steps of generating a display image of a viewport, performed by the interactive input system of FIG. **2**;

FIG. **18** shows an example of a collaboration space and a viewport showing a portion thereof;

FIGS. **19**A to **19**C show an example of determining tiles required for generating a display image of the viewport, performed by the interactive input system of FIG. **2**;

FIG. **20** shows the Quad-Tree structure of FIG. **12** after checking all nodes therein, showing the tiles to be loaded to a working memory area;

FIG. **21** shows the graphic objects loaded for generating a display image of the viewport;

FIGS. **22**A to **22**C illustrate an example of user manipulating a collaboration space; and

FIG. **23** is a perspective view of an example of the interactive input system, according to an alternative embodiment.

DETAILED DESCRIPTION

Turning now to FIG. **2**, an interactive input system is shown and is generally identified by reference numeral **100**. In this embodiment, the interactive input system is a computing system suitable for processing a collaboration space, such as an interactive whiteboard, a tablet, a laptop computer, a desktop computer, a smartphone, a PDA, or the like. Herein, methods for effective management of such collaboration spaces are described. As follows, the system supporting the process and operation of such collaboration space are set forth before the embodiments for managing same are described.

The interactive input system **100** comprises a processing structure **102**, a controlling structure **104**, memory or storage **106**, a networking structure **108**, coordinate input **110**, display output **112**, and other input and output modules **114** and **116**, all functionally interconnected by a communication channel **118**.

The processing structure **102** may be one or more single-core or multiple-core computing processors such as Intel® microprocessors offered by Intel Corporation of Santa Clara, Calif., USA, AMD® microprocessors offered by Advanced Micro Devices of Sunnyvale, Calif., USA, ARM® microprocessors manufactured by a variety of manufactures under the ARM® architecture developed by ARM Ltd. of Cambridge, UK, or the like.

The controlling structure **104** comprises a plurality of controllers, such as graphic controllers, input/output chipsets and the like, for coordinating operations of various hardware components and modules of the interactive input system **100**.

The memory **106** comprises a plurality of storage units accessible by the processing structure **102** and the controlling structure **104** for reading and/or storing data, including input data and data generated by the processing structure **102** and the controlling structure **104**. The memory **106** may be volatile and/or non-volatile, non-removable or removable storage media such as RAM, ROM, EEPROM, solid-state memory, hard disks, CD, DVD, flash memory, or the like. In use, the memory **106** is generally divided to a plurality of portions or areas for different use purposes. For example, a portion of the memory **106** may be used for long-term data storing, e.g., storing files or databases; another portion of the memory **106** may be used for caching data that is not currently used by the processing structure **102** and/or the controlling structure **104**, e.g., a so-called "virtual memory"; yet another portion of the memory **106** may be used as the system memory for temporarily storing data generated or used during processing.

In various embodiments, the memory **106** may comprise a mixture of different types of storage media, or may consist of the same type of storage medium. Moreover, different portions of the memory **106** may be local to each other. Alternatively, some portions of the memory **106** may be remote to other portions thereof. For example, some portions of the memory **106** may be the storage media on the "cloud" that can be accessed via a network, e.g., Internet.

The networking structure **108** comprises one or more networking modules for connecting to other computing devices, memory **106**, and/or networks via wired or wireless connections such as Ethernet, wireless phone channels, WiFi®, Bluetooth®, ZigBee®, or the like. In some embodiments, parallel ports, serial ports, USB connections may also be used for connecting other computing devices or networks although they are usually considered as input/output interfaces for connecting input/output devices.

The display output **112** comprises one or more display modules for displaying images, such as monitors, LCD displays, LED displays, projectors, and the like. The display output **112** may be a physically integrated part of the interactive input system **100** (e.g., the display of a laptop computer or tablet), or may be a display device physically separated from, but functionally coupled to, other components of the interactive input system **100** (e.g., the monitor of a desktop computer).

The coordinate input **110** comprises one or more input modules for one or more users to input coordinate data such as touch-sensitive screen, touch-sensitive whiteboard, trackball, computer mouse, touch-pad, or other human interface devices (HID) and the like. The coordinate input **110** may be a physically integrated part of the interactive input system **100** (e.g., the touch-pad of a laptop computer or the touch-sensitive screen of a tablet), or may be a display device physically separated from, but functionally coupled to, other components of the interactive input system **100** (e.g., a computer mouse). The coordinate input **100**, in some implementation, may be integrated with the display output **112** to form a touch-sensitive screen or touch-sensitive whiteboard.

The interactive input system **100** may also comprise other input **114** such as a keyboard, a microphone, a scanner and the like. The interactive input system may further comprise other output **116** such as a speaker, a printer, and the like.

The communication channel **118** interconnects various components **102** to **116** enabling them to transmit and receive data and control signals to/from each other. In this embodiment, the communication channel **118** is a system bus.

FIG. **3** shows an example of the interactive input system **100**, which allows one or more users to inject input such as digital ink, mouse events, commands, etc., into an executing application program, by using one or more pointers **158** such fingers, palms, fists, pen tools, erasers, cylinders or other suitable objects. As shown, the interactive input system **100** comprises a two-dimensional (2D) interactive device in the form of an interactive whiteboard (IWB) **142** mounted on a vertical support surface such as a wall surface or the like. The IWB **142** displays a collaboration space within which graphic objects are created, displayed and managed.

The IWB **142** comprises a generally planar, rectangular interactive surface **144** that is surrounded about its periphery by a bezel **146**. An ultra-short-throw projector **148**, such as that sold by SMART Technologies ULC of Calgary, Alberta, Canada, under the name "SMART UX60", is also mounted on the support surface above the IWB **142** and projects an image, for example, a computer desktop, onto the interactive surface **144**.

The IWB **142** employs machine vision to detect one or more pointers brought into a region of interest in proximity with the interactive surface **144**. The IWB **142** communicates with a general purpose computing device **152** via a universal serial bus (USB) cable **154** or other suitable wired or wireless communication link. The general purpose computing device **152** executes one or more application programs to process the output of the IWB **142** and adjusts image data that is output to the projector **148**, if required, so that the image presented on the interactive surface **144** reflects pointer activity. In this manner, the IWB **142**, general purpose computing device **152** and projector **148** allow pointer activity proximate to the interactive surface **144** to be recorded as writing or drawing or used to control execution of one or more application programs executed by the general purpose computing device **152**.

The bezel **146** is mechanically fastened to the interactive surface **144** and comprises four bezel segments that extend along the edges of the interactive surface **144**. In this embodiment, the inwardly facing surface of each bezel segment comprises a single, longitudinally extending strip or band of retro-reflective material. To take best advantage of the properties of the retro-reflective material, the bezel segments are oriented so that their inwardly facing surfaces lie in a plane generally normal to the plane of the interactive surface **144**.

A tool tray **156** is affixed to the IWB **142** adjacent the bottom bezel segment using suitable fasteners such as for example, screws, clips, adhesive, etc. As can be seen, the tool tray **156** comprises a housing having an upper surface configured to define a plurality of receptacles or slots. The receptacles are sized to receive one or more pen tools as well as an eraser tool that can be used to interact with the interactive surface **144**. Control buttons (not shown) are also provided on the upper surface of the tool tray housing to enable a user to control operation of the interactive input system **100**.

Imaging assemblies (not shown) are accommodated by the bezel **146**, with each imaging assembly being positioned adjacent a different corner of the bezel. Each of the imaging assemblies comprises an image sensor and associated lens assembly that provides the image sensor with a field of view sufficiently large as to encompass the entire interactive surface **144**. A digital signal processor (DSP) or other suitable processing device sends clock signals to the image sensor causing the image sensor to capture image frames at the desired frame rate. During image frame capture, the DSP also causes an infrared (IR) light source to illuminate and flood the region of interest over the interactive surface **144** with IR illumination. Thus, when no pointer exists within the field of view of the image sensor, the image sensor sees the illumination reflected by the retro-reflective bands on the bezel segments and captures image frames comprising a continuous bright band. When a pointer exists within the field of view of the image sensor, the pointer occludes IR illumination and appears as a dark region interrupting the bright band in captured image frames.

The imaging assemblies are oriented so that their fields of view overlap and look generally across the entire interactive surface **144**. In this manner, any pointer brought into proximity of the interactive surface **144** appears in the fields of view of the imaging assemblies and thus, is captured in image frames acquired by multiple imaging assemblies. When the imaging assemblies acquire image frames in which a pointer exists, the imaging assemblies convey pointer data to the general purpose computing device **152**.

The general purpose computing device **152** in this embodiment is a personal computer or other suitable processing device comprising, for example, a processing unit being the processing structure **102** of FIG. **2**, system memory (volatile and/or non-volatile memory) and other non-removable or removable memory (e.g., a hard disk drive, RAM, ROM, EEPROM, CD-ROM, DVD, solid-state memory, flash memory, etc.) forming the memory **106** of FIG. **2**, and a system bus, being the communication channel **118** of FIG. **2**, coupling the various computer components to the processing unit. The general purpose computing device **152** may also comprise networking capabilities using Ethernet, WiFi®, and/or other suitable network format, to enable connection to shared or remote drives, one or more networked computers, and/or other networked devices. A mouse **160** and a keyboard **162** are coupled to the general purpose computing device **152**.

The general purpose computing device **152** processes pointer data received from the imaging assemblies to resolve pointer ambiguity by combining the pointer data generated by the imaging assemblies, and to compute the locations of pointers proximate the interactive surface **144** using well known triangulation. The computed pointer locations are then recorded as writing or drawing or used an input command to control execution of an application program as described above.

In addition to computing the locations of pointers proximate to the interactive surface **144**, the general purpose computing device **152** also determines the pointer types (e.g., pen tool, finger or palm) by using pointer type data received from the IWB **142**. The pointer type data is generated for each pointer contact by the DSP of at least one of the imaging assemblies by differentiating a curve of growth derived from a horizontal intensity profile of pixels corresponding to each pointer tip in captured image frames. Specifics of methods used to determine pointer type are disclosed in U.S. Pat. No. 7,532,206 to Morrison, et al., and assigned to SMART Technologies ULC, the content of which is incorporated herein by reference in its entirety.

FIG. **4** shows the software architecture **200** of the interactive input system **100**. The software architecture **200** comprises an application layer **202**, an input interface **206**, an output interface **210** and a logical memory **220**. The application layer **202** comprises one or more application programs **204** executed or run by the processing structure **102** for performing various tasks. The input interface **206** comprises one or more input device drivers **208** for communicating with respective input devices including the coordinate input **110**, and the output interface **210** comprises one or more output device drivers **212** for communicating with respective output devices including the display output **112**. Input data received from the input devices via the input interface **206** is sent to the application layer **202**, and is processed by one or more application programs **204**. The output generated by the application programs **204** is sent to respective output devices via the output interface **210**.

The logical memory **220** is a logical mapping of the physical memory **106** for facilitating the application programs to access. In this embodiment, the logical memory **220** comprises a storage area **222** that is usually mapped to non-volatile physical memory, such as hard disks, solid state disks, flash drives and the like, for generally long-term storing data therein. The storage area **222** may alternatively be a portion of physical memory **106** for caching data that is not currently used by the processing structure **102** and/or the controlling structure **104**, e.g., a "virtual memory".

The logical memory **220** also comprises a working area **224** that is generally mapped to high-speed, and in some implementations volatile, physical memory, such as RAM, for application programs **204** to generally temporarily store data during program execution. For example, an application program **204** may load data from the storage area **222** into the working area **224**, i.e., read out data from the storage area **222** and write it into the working area **224**. The application program **204** may also store data generated during its execution in the working area **224**. The application program **204** may further store some data to the storage area **222** as required or in response to a user's command.

In some embodiments, the working area **224** may be local to the storage area **222**, e.g., both physically integrated in the same computing device. The storage area **222** and the working area **224** may be different storage media and/or managed by different function modules or controllers of the computing device. Alternatively, the storage area **222** and the working area **224** may be the same storage medium managed by the same function module or controller of the computing device. In other words, the storage area **222** and the working area **224** may be two portions of the same storage medium.

In some alternative embodiments, the working area **224** may be remote to the storage area **222**, e.g., the working area **224** being physically integrated in a computing device while the storage area **222** being a removable hard drive functionally connected to the computing device.

In some other embodiments, the working area **224** may be a memory area on another computing device, and therefore is remote to the storage area **222**. In these embodiments, a first computing device stores the collaboration space and the graphic objects therein in a storage area **222** as described above, wherein the storage area **222** is in the first computing device. Under the request of a second computing device, the first computing device loads a set of tiles determined as described above to a working area **224** in the second computing device via a wired or wireless communication channel.

Although not shown in FIG. **4**, the software structure **200** of the interactive input system **100** also comprises an operating system, such as Microsoft® Windows™, Apple® OS X®, Apple® iOS®, Linux®, etc., which manages various hardware components of the interactive system **100**, and provides support to application programs **206**.

In this embodiment, the interactive input system **100** executes the processor-readable code of an application program **204**, e.g., SMART Meeting Pro™ offered by SMART Technologies ULC of Calgary, Alberta, Canada, to manage a collaboration space. The application program, when running, creates a collaboration session, and creates or loads a collaboration space. Users may join the collaboration session and initiate user input to manipulate the collaboration space and graphic objects therein. In response to user input, the application program manipulates the collaboration space and the graphic objects therein. Here, the collaboration space is a digital space for accommodating graphic objects. As those skilled in the art appreciate, graphic objects are arranged on a (x, y) plane of the collaboration space with respective z-order such that a graphic object having a larger z-order value appears above another graphic object having a smaller z-order.

Having set forth the environment for the creation, display and interaction with such graphic objects, one turns to the management thereof.

FIG. **5** shows an example of a collaboration space **300** having a plurality of graphic objects **302** to **338** associated therewith. Generally, such a collaboration space **300** is stored in the storage area **222** for long-term storage, or as cached data, while only a portion of the collaboration space **300**, e.g., a portion of the collaboration space **300** being to be displayed on a viewport, is loaded to the working area **224** for processing. Such a data-loading process in existing interactive input systems usually requires loading of many graphic objects unrequired for rendering the display image of the viewport, causing wasted loading time and storage occupancy of the working area **224**, which generally deteriorates the performance of interactive input system, for example with slow response and/or with insufficient memory resources.

The interactive input system disclosed herein achieves improved performance by controlling the physical memory **106** using the method disclosed herein. In particular, the method disclosed herein partitions the collaboration space into tiles in a tree structure, associates each graphic object to a tile, and separately stores each tile and the graphic objects associated therewith in the storage area **222** such that, when displaying a portion of the collaboration space in a view port, the system can efficiently load required tiles and the graphic objects associated therewith into the working area **224**. The interactive input system disclosed herein therefore achieves improved performance comparing to existing systems due to less wasted time and storage resource.

Starting from the entire collaboration space **300**, the application program **204** iteratively partitions the collaboration space **300** into tiles of a predefined number of levels using a Quad-Tree algorithm, and associates graphic objects in the collaboration space with respective tiles (described in more detail later). For ease of description, the collaboration space **300** in this example is a square space with a width of 80 pixels.

Here, a Quad-Tree is a tree data structure having nodes appropriate for storing information to be retrieved on composite keys, in which each node may comprise zero (0) children nodes (so called a "leaf node" or a "leaf tile") or four (4) children nodes. Quad-Trees are often used for iteratively partitioning a two-dimensional space into four quadrants or regions. Many Quad-Tree algorithms may be used in the method and system disclosed herein. More information of Quad-Tree algorithm may be found in the academic paper entitled "Quad Trees: A Data Structure for Retrieval on Composite Keys" by Raphael Finkel and J. L. Bentley, and published in 1974 on Acta Informatica, Volume 4, Issue 1, pp. 1-9, the content of which is incorporated herein by reference in its entirety.

In this embodiment, a collaboration space is partitioned using a suitable Quad-Tree algorithm into a plurality of tiles at K levels, K>1, of which each tile corresponds to a node in the Quad-Tree structure representing a recursive subdivision of the collaboration space. In other words, the collaboration space has K representations corresponding to the K levels of the Quad-Tree. In each representation, the collaboration space is represented by the tiles in the corresponding level, i.e., the union of tiles at each level span the collaboration space. Tiles in each level have the same size. A tile at each level is either a leaf node, i.e., having zero (0) children tiles, or is subdivided into four (4) children tiles at the next level. Then, the application program **204** associates each graphic object in the collaboration space with a tile in the Quad-Tree structure. As those skilled in the art appreciate, the resulting Quad-Tree structure comprises nodes or tiles therein, the content of which comprises graphic objects associated therewith, and linkages representing the linking relationship of nodes or tiles.

FIGS. **6**A to **6**D illustrate an example of partitioning the collaboration space **300** into tiles of four levels using the Quad-Tree algorithm. For ease of illustration, the graphic objects **302** to **338** are omitted.

As shown in FIG. **6**A, the entire space **300** forms a square tile **372** at the first level L**1** having a size of 80×80 pixels.

As shown in FIG. **6**B, at the second level L**2**, the level **1** (L**1**) tile **372** is partitioned to four equal-size, square tiles, including a Top-Left (TL) tile **374**, a Top-Right (TR) tile **376**, a Bottom-Left (BL) tile **378** and a Bottom-Right (BR) tile **380**. Each second level tile has a size of 40×40 pixels.

As shown in FIG. **6**C, at the third level L**3**, each of the L**2** tiles **374** to **380** is further partitioned to four equal-size, square tiles, including a TL, TR, BL and BR tile. For example, the L**2** TL tile **374** is partitioned to a TL tile **382**, a TR tile **384**, a BL tile **386** and a BR tile **388**. As L**2** comprises four tiles, L**3** then comprises 16 tiles **382** to **412**. Each third level tile has a size of 20×20 pixels.

As shown in FIG. **6**D, at the fourth level L**4**, each of the L**3** tiles **382** to **412** is further partitioned to four equal-size, square tiles, including a TL, TR, BL and BR tile. For example, tile **382** at level L**3** is further partitioned to four equal-size, square tiles, including 1 TL tile **414**, a TR tile **416**, a BL tile **418** and a BR tile **420**. In this example, the partitioning of L**3** tiles **382** to **412** gives rise to 64 tiles, including the four tiles **414** to **420**, and 60 additional tiles generally marked with numeral **422**. Each fourth level tile has a size of 10×10 pixels.

The partitioned collaboration space **300** thus comprises a plurality of tiles at various levels after space partitioning. The partitioned collaboration space **300** may be represented by a tree structure which in this embodiment is a Quad-Tree structure wherein each node in the tree structure, except the nodes at the bottom level (also known as leaf nodes), is linked to four children nodes. The resulting Quad-Tree structure **450** is shown in FIG. **7**, in which each node represents a tile, and is marked with the numeral of the corresponding tile in FIGS. **6**A to **6**D. For ease of illustration, only a portion of nodes are shown in FIG. **7**.

The tree structure **450** originates from a root node or tile L**1** representing the Level **1** tile **372**. As tile **372** is partitioned to four tiles at L**2**, the root note L**1** thus links four children nodes at level **2**, i.e., nodes L**2**TL, L**2**TR, L**2**BL and L**2**BR representing L**2** tiles **374** to **380**, respectively. Similarly, each of the level **2** nodes also links four children nodes at level **3**. Each of the level **3** nodes further links four children nodes at level **4**.

After partitioning the collaboration space **300**, the application program **204** associates each graphic object **302** to **338** with a tile, and stores each tile, including the graphic objects associated therewith, as a separate space record in the storage area **222** of the memory **220** such that the content of each space record may be independently accessed generally without accessing the content of other space records to any substantive amount. Those skilled in the art appreciate that, in some embodiments, the application program **204** may need to retrieve a small amount of data, e.g., the header, from a second space record in order to access a first space record. However, the retrieval of such a small amount of data generally does not incur significant computational cost.

In this embodiment, a space record is stored in the storage area **222** of the memory **220** as a file. However, those skilled in the art appreciate that, a space record may alternatively be in other suitable forms, e.g., in the form of a database record in a collaboration database.

FIG. **8** is an exemplary flowchart **500** showing steps performed by the application program **204** for associating each graphic object with a tile (denoted as an object tile), and saving object tiles as space records. After the process starts (step **502**), the application program **204** checks if the collaboration space **300** comprises any graphic objects to be processed (step **504**). If so, the application program **204** selects a graphic object (step **506**), and finds a smallest tile, i.e., a tile having the smallest size, in the partitioned collaboration space that can substantially accommodate the selected graphic object, and associates the selected graphic object therewith (step **508**). Here, the term "substantially" means that the determined tile can accommodate a predefined portion, usually a predefined major portion that is greater than 50%, e.g., 80%, 90% or 100% in various embodiments, of the selected graphic object or can accommodate the entirety of the selected graphic object.

As will be described in more detail below, to determine whether or not a tile can substantially accommodate the selected graphic object, a comparison may be made between the tile and the graphic object to determine if the size of said tile is larger than that of at least a predefined portion of the graphic object; or alternatively, a comparison may be made between the tile and a bounding region of the graphic object to determine if the size of said tile is larger than that of at least a predefined portion of the bounding region of the graphic object.

Here, a bounding region is a shape having the smallest size and completely enclosing the graphic object. Of course, a shape having a size larger than the smallest size and completely enclosing the graphic object may alternatively be used as the bounding region. Generally, a bounding region has a simplified shape for simplifying calculation. Depending on the implementation, the bounding region may be a circle, a rectangle, an oval or other suitable shapes.

Following step **508**, the process then loops back to step **504** to check if the collaboration space **300** still comprises any unprocessed graphic objects.

FIG. **9** shows the detailed steps of associating a graphic object with a tile (i.e., step **508** of FIG. **8**). At step **532**, the application program **204** first calculates a bounding region for the selected graphic object. Here, the bounding region is defined as a bounding circle which is the smallest circle completely enclosing the graphic object. The application program **204** determines the radius R and center (x_c, y_c) of the bounding circle. Then, the application program determines a suitable tile level based on the radius R of the bounding circle (step **534**), and then determines the tile for the selected graphic object to associate therewith, based on the center (x_c, y_c) of the bounding circle (step **536**).

FIG. **10** shows the detailed steps of determining a suitable tile level for the selected graphic object (i.e., step **534** of FIG. **9**). At step **552**, the application program **204** starts from the top level by setting a level reference L to the top level L**1**. Then, at step **554**, the application program **204** compares the radius R of the bounding circle of the selected graphic object with the tile width W_L at this level weighted by a tile width weighting factor C_w, i.e., checking whether or not $R>C_wW_L$. In this embodiment, the tile width weighting factor C_w equals to 0.25.

With tile width weighting factor C_w being 0.25, the determined tile can receive the entirety of the selected graphic object.

If at step **554**, it is determined that R is larger than C_wW_L (the "Yes" branch of step **554**), the process then goes to step **560**, and the application program **204** sets the tile level as the level reference L. The process then goes to step **536** of FIG. **9**.

If at step **554**, it is determined that R is smaller than or equal to C_wW_L (the "No" branch of step **554**), the application program **204** further checks if the level reference L refers to the bottom level having the smallest tiles (step **556**). If not, the application program **204** sets the level reference L to the next lower level (step **558**), and the process loops back to step **554** to check if the graphic object belongs to this level.

If at step **556**, the level reference L refers to the bottom level, the process then goes to step **560**, and the application program **204** sets the tile level as the level reference L. The process then returns to step **536** of FIG. **9**.

The iteration of step **554** generally finds a tile level for a graphic object to be the tile level of the smallest tiles that the width thereof is larger than or equal to the diameter of the bounding circle of the graphic object weighted by a factor C_d. In the embodiment wherein $C_d=1$, the iteration of step **554** generally finds a tile level for a graphic object to be the tile level of the smallest tiles that the width thereof is larger than or equal to the diameter of the bounding circle of the graphic object.

In the embodiment wherein the collaboration space are partitioned to square tiles, and the width of a parent tile is twice of that of its child tile, $C_d=1/(4C_w)$. Further, the tile level L to be found for a graphic object has to satisfy:

$$4RC_d>W_L>=2RC_d, \text{ or}$$

$$R/C_w>W_L>=R/(2C_w),$$

where R is radius of the bounding circle of the graphic object, and W_L is the width of tiles at level L.

Referring back to FIG. **9**, after determining the tile level at step **534**, the application program **204** finds the tile in the determined tile level for the selected graphic object to associate therewith, based on the center (x_c, y_c) of the bounding circle (step **536**), which in this embodiment is the particular tile in the determined tile level that the point (x_c, y_c) falls within. The process then goes to step **504** of FIG. **8** to process any further graphic objects.

Referring back to FIG. **8**, if at step **504** the application program **204** determines that all graphic objects in the collaboration space **300** have been processed, i.e., having been associated with a tile, the application program **204** then stores each tile, including the objects associated therewith, in the storage area **222** as an independently accesible record. In one particular embodiment, each record may be a file stored in the storage area **222** of the memory **220**. Moreover, in this embodiment, the application program only stores the tiles that comprise at least one graphic object associated therewith (so-called "non-empty nodes" or "non-empty tiles"), i.e., the object tiles. Those skilled in the art appreciate that the application program may also store the tiles having no graphic object associated therewith but are linked intermediate between the root node L**1** and a non-empty node in the Quad-Tree structure of FIG. **7** (so-called "empty-but-intermediate nodes" or "empty-but-intermediate tiles") for the ease of reconstructing the Quad-Tree structure when loading tiles of the collaboration space to the working area **224**.

FIGS. **11**A to **11**C show an example of determining a tile to associate with the graphic object **302** of FIG. **5**. As described above, the exemplary collaboration space **300** is a square space with a width of 80 pixels. After partitioning the collaboration space **300** to tiles in four levels, the tile width at levels L**1**, L**2**, L**3** and L**4** are: W_1=80 pixels, W_2=40 pixels, W_3=20 pixels, and W_4=10 pixels. For ease of illustration, the x-y coordinates of the collaboration space **300** is defined as having the origin at the top-left corner thereof with the x-axis increasing towards the right-hand side and the y-axis increasing downwardly.

Following the process in FIGS. **9** and **10**, the application program **204** first determines that the radius R of a bounding circle **602** of the graphic object **302** is 9 pixels, and the x-y coordinates of center **604** of the bounding circle **602** is (15, 42) (step **532**). Referring to FIG. **11**A, the application program starts by setting the level reference L to the top level L**1** (step **552**), and compares R with C_wW_1 (step **554**). As R=9, $C_wW_1=0.25\times80=20$ and thus $R<C_wW_1$, the application program then sets the level reference L to the next lower level L**2** (step **558**).

As shown in FIG. **11**B, the application program compares R with C_wW_2 (step **554**). As $R=9<C_wW_2=0.25\times40=10$, the application program then sets the level reference L to the next lower level L**3** (step **558**).

As shown in FIG. **11**C, the application program compares R with C_wW_3 (step **554**). As $R=9>C_wW_3=0.25\times20=5$, the tile level for the graphic object **302** is therefore L**3** (step **558**).

After determining the suitable tile level, the application program **204** then determines that, among the tiles **382** to **412** at level L**3** (see FIG. **6**C), tile **398** overlaps with the center **604** of the bounding circle **602** of the graphic object **302**, which is the TL tile of the tile **378** at level L**2**, which in turn is the BL tile of the top level tile **372** (step **536**). Therefore, the graphic object **302** is associated with the tile **398**.

Following the same process, other graphic objects **304** to **338** in the collaboration space **300** are also associated with a respective tile. After all graphic objects are associated with their respective tiles, the Quad-Tree structure **450'** having graphic objects associated therewith is shown in FIG. **12**, which only shows the non-empty nodes and the nodes linked intermediate between the root node and a non-empty node. The tiles in the Quad-Tree structure **450'**, including the non-empty tiles and the empty-but-intermediate tiles empty but linking intermediate between the root node L**1** and a non-empty node, are stored in the storage area **222** of the memory **220**.

In the resulting Quad-Tree structure **450'**, graphic objects are associated with tiles in different levels in accordance with their sizes. Generally, larger graphic objects are associated with tiles of higher levels, and smaller graphic objects are associated with tiles of lower levels. Graphic objects in the collaboration space **300** are thus generally sorted by size in the resulting Quad-Tree structure **450'**.

Those skilled in the art appreciate that, partitioning a collaboration space into a Quad-Tree structure and associating graphic objects with tiles of various levels does not change the z-order of any graphic object. As described later, when displaying the collaboration space in a viewport, which may be a display device of the interactive input system, the application program **204** determines tiles required for generating a display image of the viewport, and loads the required tiles from the storage area **222** to the working area **224**. The application program **204** then renders the graphic objects in the loaded tiles according to their respective z-order to generate a display image of the viewport for display.

The application program **204** maintains the linkages of the Quad-Tree structure **450'** and the required tiles, e.g., the tiles required for forming the display image of a viewport, in the working area **224** of the memory **220** during the collaboration session, and stores the Quad-Tree structure **450'**, including the linkages and tiles therein, to the storage area **222** of the memory **220** when the collaboration session is over. Those skilled in the art appreciate that, in some embodiments, the application program **204** may store the Quad-Tree structure **450'** to the storage area **222** in response to a user's command during the collaboration session and/or when the collaboration session is over.

As described above, each tile of the Quad-Tree structure **450'** is stored as a separate space record in the storage area **222**. The linkages of the Quad-Tree structure **450'**, on the other hand, may be stored in the storage area **222** in any suitable manner in various embodiments.

For example, in one embodiment, the linkages of the Quad-Tree structure **450'** is stored in the storage area **222** as a master record. In another embodiment, the linkages of the Quad-Tree structure **450'** is stored in the space record of the root tile. In yet another embodiment, the application program **204** does not store the linkages of the Quad-Tree structure **450'**. Rather, it records the space record of the root tile in a directory in the storage area **222**, and stores in each tile the links to the children tiles thereof. In this embodiment, the application program **204** builds the linkages of the Quad-Tree structure **450'** each time when loading the collaboration space **300**.

In the above embodiment described in FIG. **10**, the application program **204** iteratively checks all levels to determine a suitable tile level for a selected graphic object, which may be computationally costly if the collaboration space **300** is partitioned to tiles of a large number of levels. In a preferred embodiment, the application program **204** directly calculates the tile for a selected graphic object to associate therewith.

Let L=1, 2, . . . , N represent the partition level with L=1 representing the top level and L=N representing the bottom level. Let W_L represent the tile width at level L. We have $W_{L-1}=2W_L$, for L=2, 3, . . . , N. Thus, W_1 represents the width of the entire collaboration space **300**, W_N represents the smallest tile width in the partitioned collaboration space **300**, and

$$W_N=W_1/2\hat{}(N-1),$$

where x^y represents the result of x to the power of y.

To determine the suitable tile level for a graphic object having a bounding circle with radius R and center (x_c, y_c), the application program first calculates a level L_c in terms of the total number of levels N, bounding circle radius R and the collaboration space width W_1 as:

$$\begin{aligned} L_c &= \log_2(2R/W_N) \qquad (1)\\ &= \log_2(2)+\log_2(R/(W_1/2\hat{}(N-1)))\\ &= N+\log_2(R)-\log_2(W_1) \end{aligned}$$

where $\log_2(x)$ is the function for calculating the logarithm of x to base 2. Then, the application program calculates a level index i as:

$$i=\text{CEILING}(L_c),\ \text{if}\ L_c>0,\ \text{or} \tag{2a}$$

$$i=0,\ \text{if}\ L_c\leq 0, \tag{2b}$$

where CEILING(x) is the function for calculating the smallest integer that is larger than or equal to x. The suitable tile level L_T is calculated as:

$$L_T=N-i, \tag{3}$$

and the tile width at level L_T is:

$$W_T=W_N 2\hat{}i. \tag{4}$$

Now, let (X_T, Y_T) represents the index of the tile to be associated with the graphic object, referring to the tile at the L_T level positioned at the X_T-th column of tile counting from the leftmost column and the Y_T-th row counting from the topmost row, where $X_T\geq 0$ and $Y_T\geq 0$ are integers. Then, (X_T, Y_T) is determined as:

$$X_T=\text{FLOOR}(x_c/W_T), \tag{5}$$

$$Y_T=\text{FLOOR}(y_c/W_T), \tag{6}$$

where FLOOR(x) is the function for calculating the largest integer that is smaller than or equal to x.

FIG. **13** shows an example of directly calculating the tile for associating with the graphic object **302** of FIG. **5**. As described above, the radius R of a bounding circle **602** of the graphic object **302** is R=9 pixels, and the x-y coordinates of center **604** of the bounding circle **602** is $(X_c, Y_c)=(15, 42)$. The 80-pixel-by-80-pixel collaboration space **300** is partitioned to N=4 levels, and the smallest tile width is thus $W_N=10$ pixels.

Using equations (1) to (3) the application program **204** determines the calculated level L_c as $L_c=\log_2(2R/W_N)=N+\log_2(R)-\log_2(W_1)\approx 0.85$. Thus the level index i=CEILING $(L_c)=1$ as $L_c>0$, and the suitable tile level $L_T=N-i=3$.

Using equation (4), the tile width at level **3** is $W_T=W_N 2\hat{}i=20$ pixels, and the tile indices $X_T=\text{FLOOR}(x_c/W_T)=0$ and $Y_T=\text{FLOOR}(y_c/W_T)=2$, i.e., the tile to be associated with the graphic object **302** is the (0, 2) tile at level **3**, the tile denoted by numeral **398**.

FIG. **14** illustrates the data structure **640** of the partitioned collaboration space **300** in this embodiment, with the tile **398** showing with a hatched background for indicating that it comprises an associated graphic object, after the above process of determining the tile for the graphic object **302**. In FIG. **14**, tiles in each level are shown as an array for illustrative purpose. However, in implementation, the tiles in each level are organized in a hash table with the indices of the array being used as keys. Such an implementation allows the application program to only allocate memory storage for non-empty tiles. As a collaboration space usually comprises a relatively small number of non-empty tiles, a small number of space records are usually needed for storing the collaboration space **300**.

The method of directly calculating the tile for a graphic object without iterating all levels of tiles gives rise to a "constant" computational time regardless of the number of levels that the collaboration space **300** is partitioned to (i.e., independent of N), and allows generally fast insertion of a graphic object to the collaboration space **300** when a user inserts a new graphic object or moves an existing graphic object to a new location that requires the application program **204** to move the graphic object to a new tile; in other words, the graphic object has to be removed from the tile it was originally associated therewith, and be re-associated with another tile.

Partitioning a collaboration space into tiles of various levels and storing each tile separately allows the application program **204** to efficiently use the working area **224** of the memory **220**.

FIG. **15** is a simplified block diagram showing the software structure **680** of the interactive input system **100** during a collaboration session. As shown, the collaboration space **300** is stored in the storage area **222** of the memory **220** as space records **682**. During collaboration, the application program **204** maintains the Quad-Tree structure of the collaboration space, and only loads required tiles or space records **684** from the storage area **222** to the working area **224**. The application program **204** manipulates the loaded tiles **684** in response to input **206**, and sends the manipulation results to the output **210** for, e.g., forming a display image to be shown on a display. The processed tiles **684** may be stored to the storage area **222** as stored space records **682**.

In response to input **206**, the application program **204** may also load other tiles from the storage area **222** into the working area **224**, and remove some tiles from the working area **224**. For example, a user may initiate a command to display another portion of the collaboration space **300** on a viewport. As described before, the viewport in this embodiment is a display device local to the memory **106**.

In response to the user's command, the application program **204** removes the tiles no longer necessary for display from the working area **224**, and determines the tiles required for forming a display image of the viewport, and loads the required tiles from the storage area **222** into the working area **224** if they have not been loaded.

In one embodiment, the application program **204** conducts hit tests between tiles and the viewport to determine the tiles required for forming a display image of the viewport. FIG. **16** is a flowchart **700** showing steps performed by the application program **204** for determining the tiles to be loaded for generating a display image of a viewport.

The process starts when a display image of a viewport is to be generated for displaying the collaboration space **300** therein (step **702**). After the process starts, the application program traverses the linkages of the Quad-Tree structure **450'** of the partitioned collaboration space **300** and determines the tiles to be loaded for generating the display image (step **704**). Those skilled in the art appreciate that any suitable tree-search algorithm known in the art, e.g., a depth-first algorithm or a breadth-first algorithm, may be used for traversing the linkages of the Quad-Tree structure **450'**. The detail of such algorithm is thus omitted, and is generally described as "selecting next tile".

FIG. **17** shows the detail of step **704** of FIG. **16** of finding required tiles to be loaded. At step **722**, the application program **204** selects the root tile or node of the Quad-Tree structure **450'** to determine if the root tile is required to be loaded. At step **724**, the application program **204** defines a zone for the selected tile. At this step, the zone is defined as an area concentric with the selected tile, with a width or dimension equal to that of the selected tile weighted by a predefined factor C_b, where $C_b>1$. In other words, the zone is an area enlarged from the area of the selected tile with each of its four sides enlarged from the corresponding side of the selected tile by $(C_b-1)/2$. In this embodiment, the factor C_b is 2 for a 50% buffering.

The application program **204** then performs a hit test between the defined zone and the viewport to determine if they are overlapped (step **726**). If the defined zone overlaps with the viewport (step **728**), the application program **204** then marks the selected tile as a required tile to be loaded, and marks it as checked (step **730**). The process then goes to iteration step **734**.

Alternatively, at step **728**, if the defined zone does not overlap with the viewport, the application program **204** then marks the selected tile as a non-required not to be loaded, and marks the selected tile and all of its children tiles, including children tiles directly linked thereto and children tiles indirectly linked thereto via one or more intermediate children tiles of the selected tile, as non-required tiles and as checked (step **732**).

At iteration step **734**, the application program **204** checks if all tiles have been checked. If not, the application program **204** selects the next tile (step **736**), and the process loops back to step **724**.

If, at step **734**, it is determined that all tiles in the Quad-Tree structure **450'** have been checked, the process then returns to step **706** of FIG. **16**.

Referring back to FIG. **16**, at step **706**, the application program **204** loads the required tiles. The application program **204** then uses the content of these required tiles to generate a display image for the viewport to display (step **708**). The process ends after the generated display image is sent to the output for display (step **710**).

FIG. **18** shows an example of generating a display image of a viewport **800** displaying a portion of a collaboration space **300** of FIG. **5**. In this example, a user has zoomed in the display of the collaboration space such that the viewport **800** only displays a portion of the collaboration space **300** fully encompassing graphic objects **328**, **330** and **336**, and partially encompassing graphic objects **310**, **326** and **338**.

As described above, the collaboration space **300** has been partitioned to tiles in four levels as shown in FIG. **12**. Following the process of FIGS. **16** and **17**, the application program **204** traverses the linkages of the Quad-Tree structure **450'** of the partitioned collaboration space **300**. The application program **204** starts the tree traversal from the root node L**1**, as shown in this case, tile **372**. As tile **372** encompasses the entire collaboration space **300**, it always overlaps with the viewport **800** and is therefore marked as a required tile to be loaded. However, as tile **372** is not associated with any graphic object, loading tile required **372** does not cost any computational time or any space in the working area **224** that is normally associated with loading a graphic object.

Then, the application program **204** checks whether or not the first node at level **2**, i.e., the L**2**TL tile **374** at level **2**, shall be loaded.

As shown in FIG. **19**A, the application program first defines a zone **802** concentric with the tile **374**, with a width equal to that of the tile **374** weighted by a predefined factor C_b of 2 (step **724**). In other words, the zone **802** is an area enlarged from the area of the tile **374** with each of its four sides enlarged from the corresponding side of the tile **374** by $(C_b-1)/2=50\%$. In FIG. **19**A, the enlargement from tile **374** on its left and top sides is not shown as it goes beyond the collaboration space **300**.

The application program **204** then performs a hit test between the defined zone **802** and the viewport **800** (step **726**), and determines that the defined zone **802** overlaps with the viewport **800** (the "Yes" branch of step **728**). Tile **374** is thus marked as a required tile to be loaded (step **730**). As tile **374** is associated with the graphic object **310**, loading the required tile **374** will load the graphic object **310** into the working area **224**.

In this example, the application program **204** uses a depth-first algorithm to traverse the linkages of the Quad-Tree structure **450'**. Therefore, after checking the top-left tile **374** at level **2**, the application program **204** checks whether or not its child node L3TL, i.e., the tile **382** at level **3**, shall also be required to be loaded.

As shown in FIG. **19**B, the application program first defines a zone **804** concentric with the tile **382**, with a width equal to that of the tile **382** weighted by a predefined factor C_b of 2 (step **724**). Again, in FIG. **19**B, the enlargement from tile **382** on its left and top sides is not shown as it goes beyond the collaboration space **300**.

The application program **204** then performs a hit test between the defined zone **804** and the viewport **800** (step **726**), and determines that the defined zone **804** does not overlap with the viewport **800** (the "No" branch of step **728**). Tile **382** and its child node L**4**BL, i.e., tile **418**, are thus marked as a non-required tile not to be loaded (step **732**).

The process repeats to check other tiles in the Quad-Tree structure **450'**. FIG. **19**C shows the checking of the level **3** node L**3**TR, i.e., tile **400**. Similar as above, the application program **204** checks whether or not the node L**3**TR linked to the L**2**BL node, i.e., the tile **400** at level **3**, shall be loaded.

As shown in FIG. **19**C, the application program first defines a zone **806** concentric with the tile **400**, with a width equal to that of the tile **400** weighted by a predefined factor C_b of 2 (step **724**). The application program **204** then performs a hit test between the defined zone **806** and the viewport **800** (step **726**), and determines that the defined zone **806** overlaps with the viewport **800** (the "Yes" branch of step **728**). Tile **400** is thus marked as a required tile to be loaded (step **730**). As tile **400** is associated with the graphic object **326**, loading tile **400** will load the graphic object **326** into the working area **224**.

FIG. **20** shows the Quad-Tree structure **450'** after checking all nodes therein. The nodes of the required tiles to be loaded to the working area **224** are hatched therein. FIG. **21** also illustrates the graphic objects that are loaded to the working area **224**. As can be seen, all graphic objects **310**, **326**, **328**, **330**, **336** and **338** that overlap with the viewport **800** are loaded into the working area **224**.

The graphic object **324** is also loaded into the working area **224** as the defined zone **810** enlarged from the area of the tile **422**A that the graphic object **324** is associated therewith does overlap with the viewport **800**. However, it is not visible in the viewport **800**. Although loading the graphic object **324** causes extra overhead, loading it may be beneficial when a user moves the viewport to encompass the graphic object **324**, in which case the preloaded graphic object **324** in the working area **224** facilitates fast generation of viewport display.

FIGS. **22**A to **22**C illustrate an example of user manipulation of the collaboration space **300**. In this example, the interactive input system **100** executes the application program **204** in a full screen mode to use the entire interactive surface **144** for displaying the collaboration space **300**. Therefore, the entire interactive surface **144** is the viewport **800**, displaying a portion of the collaboration space **300**. The application program **204** uses the above-mentioned method to determine tiles necessary for forming the display image of the viewport **800**, loads the determined tiles and forms the display image of the viewport **800**, as shown in FIG. **22**A. The application program **204** also superimposes a toolbar **822** having a plurality of tool buttons **824** over the displayed collaboration space **300**, which provides a plurality of tools for user to manipulate the collaboration space **300** and graphic objects therein. A user may apply a pointer **826**, such as a finger, in contact with the interactive surface **144** at a location overlapping the background of the collaboration space **300**, and slide the pointer **826** towards upper-left as indicated by the arrow **828**, to apply a panning gesture to the collaboration space **300**. In response to the panning gesture, the application program "moves" the collaboration space **300** along the direction of the panning gesture, or equivalently, moves the viewport **800** in a position opposite to that of the panning gesture. The application program **204** uses the above-mentioned method to determine in real-time the tiles necessary for forming the display image of the viewport **800**, loads the determined tiles, and forms the display image of the viewport **800** to update the display, as shown in FIG. **22**B.

In FIG. **22**B, the user may apply two fingers **826** and **830** in contact with the interactive surface **144** overlapping the background of the collaboration space **300**, and move the fingers **826** and **830** towards each other as indicated by the arrows **832** and **834**, respectively, to apply a zooming-out gesture. In response, the application program **204** zooms out the display of the collaboration space **300**, as shown in FIG. **22**C.

In FIG. **22**C, the user further applies a pen tool **836** in contact with the interactive surface **144** and writes thereon. In response, the application program **204** detects the movement of the pen tool **826** and injects annotation **838** into the collaboration space. The newly injected annotation **838** is inserted to the Quad-Tree structure **450'** and associated with a tile following the method described above.

In above embodiments, the application program **204** determines the required tiles necessary for forming a display image of the viewport **800**, and forms a display image of the viewport **800**. The display image is displayed after all required tiles have been loaded to the working area and the content therein have been rendered to the display image. In an alternative embodiment, the application program **204** renders the display image immediately after a required tile is loaded, and displays the updated display image immediately after rendering. A progressive display effect is thus achieved wherein graphic objects appear in the viewport one after another. For example, if a top-down, breadth-first, tree-traversal algorithm is used for traversing the Quad-Tree structure from the root node, larger graphic objects are generally displayed before smaller graphic objects. If a bottom-up, breadth-first, tree-traversal algorithm is used for traversing the Quad-Tree structure, smaller graphic objects are generally displayed before larger graphic objects. If a depth-first, tree-traversal algorithm is used for traversing the Quad-Tree structure, a "localized" progressive display effect is achieved wherein graphic objects in a first area of the collaboration space are first displayed, and then are those in another successive area thereof.

In above embodiments, a collaboration space is partitioned to tiles of a predefined number of levels. In an alternative embodiment, the application program **204** dynamically determines the number of partitioning levels. For example, when the application program creates a new collaboration space, a top level (i.e., the first level) tile is defined as the entire collaboration space. When a user inserts a graphic object into the collaboration space, the application program calculates in real-time a tile level n for a square tile with a width W_n

$$W_n=W_1 2\hat{}(-n+1),$$

where W_1 is the width of the top level tile, and n is the tile level for associating the newly created graphic object. Here, the n is calculated as the largest positive integer such that the square tile of width W is sufficient for accommodating a substantive portion of the newly created graphic object, e.g., the radius R of the bounding circle of the newly created graphic object being larger than C_wW_n, with the tile width weighting factor C_w=0.25. As those skilled in the art appreciate, the partitioning level n increases when a small graphic object is inserted into the collaboration space.

In another embodiment, the application program **204** does not partition the collaboration space until the collaboration space is saved to the storage area **222**. When the application program **204** saves the collaboration space to the storage area **222** for long-term storage or for caching, the application program **204** determines the smallest graphic object therein, and calculates the width of the smallest tile in the Quad-Tree structure as

$$W=W_1 2\hat{}(-n+1),$$

where W_1 is the width of the collaboration space, and n is the level of the smallest tile. Here, the n is calculated as the largest positive integer such that the square tile of width W is sufficient for accommodating a substantive portion of the smallest graphic object, e.g., the radius R of the bounding circle of the smallest graphic object is larger than C_wW_n with the tile width weighting factor C_w=0.25.

Although in above embodiments, the Quad-Tree structure is built top-down, i.e., from the largest tile at the top level to the smallest tile at the bottom level, in an alternative embodiment, the Quad-Tree structure may be built bottom-up, i.e., from the smallest tile at the bottom level to the largest tile at the top level, after determining the size of the smallest tile.

In another embodiment, the application program **204** does not partition an empty collaboration space (i.e., a collaboration space having no graphic object) until a graphic object has been created therein, at which time a smallest square tile (denoted as the reference tile) that can substantially accommodate the graphic object is determined for the graphic object to associate therewith. The width W_r of this tile is used as a reference tile width. When more graphic objects are created, the application program **204** may define new tiles at the same, upper or lower level of the reference tile with a width being $W_r2\hat{}m$, where m is an integer, by comparing the radius of the bounding circle of the graphic object and the tile width as described above. Thus, in this embodiment, a Quad-Tree structure **450'** may be built from a tile at an intermediate level, and may be useful for managing an "infinite" collaboration space that appears to users to be infinite in size.

In above embodiments, the tile width weighting factor C_w is predefined as 0.25 such that any graphic object is associated with a tile that can fully accommodate the graphic object. In another embodiment, the tile width weighting factor C_w may be a predefined factor smaller than 0.25 and greater than 0.

In yet another embodiment, the tile width weighting factor C_w may be a predefined factor greater than 0.25 but generally smaller than 0.5. In this embodiment, a graphic object may be associated with a tile that can only accommodate a major portion of the graphic object.

In another embodiment, the application program **204** allows users to choose a desired tile width weighting factor C_w. In addition, the weighting factor C_w may be specified at the tile level so that tiles at different level may have different weighting factors.

Although in above embodiments, the weighting factor C_b is predefined as 2, in other embodiments, the application program **204** may use a different weighting factor C_b. In another embodiment, the application program **204** allows users to choose a desired weighting factor C_b.

In above embodiments, the collaboration space **300** is a square space. In an alternative embodiment, the collaboration space may be a rectangular space. In this embodiment, a top level square tile is defined as a square tile that accommodates the entire collaboration space.

In above embodiments, a collaboration space is partitioned into a plurality of square tiles. In another embodiment, a collaboration space is partitioned into a plurality of rectangular tiles. In this embodiment, the application program determines the tile that a graphic object is associated therewith by finding the smallest tile in the partitioned collaboration space such that an imaginary square tile of width W_v, where W_v equals to the smaller of the length and width of the rectangular tile, can substantially accommodate the selected graphic object.

In yet another embodiment, in which the collaboration space is partitioned into rectangular tiles with a tile length-to-width ratio R_T, the application program first virtually stretches a graphic object by stretching its width to a width of $W_j R_T$, where W_j is the width of the graphic object. The application program then determines the tile for the graphic object to associate therewith by finding the smallest tile in the partitioned collaboration space such that an imaginary square tile of width W_k, where W_k equals to the length of the rectangular tile, can substantially accommodate the stretched imaginary object.

In above embodiments, when a user moves the viewport around the collaboration space, the application program **204** determines in real-time the tiles required for forming the display image of the viewport. The application program **204** then loads the required but not yet loaded tiles into the working area **224**, and unloads or otherwise deletes the no-longer-required tiles from the working area **224**.

When a user quickly moves the viewport around the collaboration space, loading and unloading tiles may cause delays in displaying the collaboration space. In an alternative embodiment, the application program **204** first renders and displays bounding boxes or regions for required tiles to be load, but not yet loaded, to give users a visual cue that some graphic objects are still loading, and replaces each bounding box by the image of the corresponding tile when the graphic objects therein have been loaded.

In another embodiment, the application program **204**, after loading a tile and determines the graphic objects therein, first renders and displays bounding boxes for graphic objects to be rendered, but not yet rendered, to give users a visual cue that some graphic objects are still loading, and replaces each bounding box by the image of the corresponding graphic object when the graphic object has been rendered.

In yet another embodiment, the application program **204** also partitions the collaboration space into a plurality of sections or grids, and generates and maintains an alternative representation, such as a thumbnail, for each section. When the viewport is moved to another location of the collaboration space, the application program **204** first display the thumbnail(s) of the section(s) to be shown in the viewport, and replaces the thumbnail(s) by the display image after required tiles are loaded and the display image is generated.

In still another embodiment, a buffer is added to the viewport by expanding the viewport for a predefined percentage on each of its four sides, and the application program **204** performs a hit test between the expanded viewport and the defined zone for each tile in the Quad-Tree to determine if the tile is required to be loaded. Performance of loading and displaying graphic objects during viewport moving may then be improved with the expense of extra memory usage. In another embodiment, the application program **204** calculates a velocity vector, estimates the moving distance of the viewport, and expands the viewport towards the direction of the calculated velocity vector with a size determined based on the magnitude of the calculated velocity vector.

In another embodiment, the application program **204** partitions a collaboration space into tiles of various levels as described above, and associates each graphic object with a tile only based on the overlapping of the center of the graphic object and the tile. The graphic objects in the obtained Quad-Tree structure are therefore not sorted by size. In other words, a larger size graphic object may be associated with a smaller tile at a lower level while a smaller size graphic object may be associated with a larger tile at a higher level.

In above embodiments, the storage area **222** and the working area **204** are local to the viewport. For example, the storage area **222**, the working area **204** and the viewport may be an internal hard disk, the RAM and the display of a computing device. Alternatively, the storage area **222** may be an external storage, e.g., an external hard drive, local to the computing device that comprises the working area **224** and the viewport, and connecting thereto via a suitable connection such as a USB cable. Alternatively, the storage area **222**, as an external storage, may be a remote storage accessible via a network such as the Internet, a Local Area Network (LAN), a wide area network (WAN) or the like, via suitable wired and wireless networking connections.

In an alternative embodiment as shown in FIG. **23**, the interactive input system **100** comprises two or more computing devices **932**, such as server computers, computing devices having interactive whiteboards, desktop computers, laptops, smartphones and the like, interconnected by a network **934**, such as the Internet, a LAN, a WAN or the like, via suitable wired and wireless networking connections.

Depending on implementation, the server computer may be a stand-along computing device, or alternatively, a client computing device in the interactive input system may act as a server computer while also being used by a user. The server computer executes a server-side application program for managing one or more collaboration session for users of client computing devices **932** in the system. The server-side application program communicates with each computing device joined to the collaboration session, and shares content of the collaboration session therewith. A client program runs on each client computing device in the collaboration session for displaying the collaboration space or a portion thereof to the user via a viewport and for receiving user input.

During a collaboration session, the server-side application program manages one or more collaboration spaces, partitioning each collaboration space and saving the partitioned collaboration space(s) to a storage or memory functionally associated with the server computer(s), as described above. The server-side application program loads and unloads tiles as described above in response to user input received from users in the collaboration session, including user input received from an input device directly connected to the computing device running the application program (when the server computer is also used as a client computing device), and user input received from a remote client computing device via the network **934**.

In this embodiment, the memory **106** of the system **100** comprises the memory or storage of all servers and client computing devices therein, and the communication channel **118** comprises the system bus in each of the servers and client computing devices in the system and the network **934** interconnecting the servers and client computing devices. The storage area **222** may be the non-volatile physical memory, e.g., hard disks, of the servers, and the working area **224** may be a portion of the RAM of a client computing device that the client program is accessing. The storage area **222** is thus remote to the working area **224**. Moreover, as the view port **800** may be the display of a client computing device, the storage area **222** may be remote to the view port **800**.

When a user of a client computing device moves his/her viewport, the client program sends a viewport moving command to the server side application program. The server side application program determines the required tiles to be loaded, as described above, and loads the required tiles from the storage area **222** in one or more servers to the working area **224** in the client computing device via the network **934**.

In yet another embodiment, the interactive input system **100** comprises two or more computing devices **932** as shown in FIG. **23**. However, in this embodiment, the storage area **222** and is the non-volatile physical memory, e.g., hard disks, of the servers, and the working area **224** is a portion of the RAM of the servers. When a user of a client computing device moves their viewport, the client program sends a viewport moving command to the server side application program. The server side application program determines the required tiles to be loaded, as described above, loads the required tiles from the storage area **222** in the one or more servers to the working area **224**, generates the view port image using loaded tiles, and sends the generated view port image to client computing device via the network **934** for display.

In above embodiments, the application program is implemented as a stand-alone program executable by the operating system. In an alternative embodiment, the application program is implemented as a web-server application hosted on a server, a server farm, or a cloud service wherein a server side program module manages the collaboration space, and each one of one or more client side program modules are executed inside a respective web browser, e.g., Microsoft® Internet Explorer®, Apple® Safari®, Google Chrome™, Mozilla Firefox®, Opera™ browser, Dolphin browser, or the like, for displaying the collaboration space or a portion thereof to the user via a viewport and for receiving user input.

In above embodiments, the application program **204** first determines a tile level for a selected graphic object, and then finds a required tile in the determined tile level that overlaps with the center of the selected graphic object for associating therewith. In some alternative embodiments, the application program **204** finds a required tile by finding a tile in the determined tile level that overlaps with a substantive portion of, including the entirety of, the selected graphic object.

In above embodiments, the application program **204** stores the non-empty tiles and the empty-but-intermediate tiles empty but linking intermediate between the root node L**1** and a non-empty node in the Quad-Tree structure. In an alternative embodiment, the application program **204** only stores non-empty tiles, and the linkages thereof. In an alternative embodiment, the application program **204** stores the entire Quad-Tree structure, including all empty and non-empty tiles.

In yet other embodiments, the storage area **222** may comprise RAM memory while the working area **224** may comprise cache memory having a faster access speed than the RAM used in storage area **222**.

Although embodiments have been described above with reference to the accompanying drawings, those of skill in the art will appreciate that variations and modifications may be made without departing from the scope thereof as defined by the appended claims.

What is claimed is:

1. A method of controlling one or more memory devices of an interactive input system for storing a collaboration space, said collaboration space having one or more graphic objects therein, the method comprising:

partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at the same level having a same size, each tile at a level either being a leaf node or being subdivided into four smaller tiles at the next level;

determining one or more object tiles, each object tile being a tile of said plurality of tiles and associated with at least one of said one or more graphic objects; and

controlling a first memory of said one or more memory devices to store the one or more object tiles therein, each object tile being stored in said first memory as a separate record that may be independently accessed;

wherein the one or more object tiles are determined by:

for each graphic object,

determining a tile level L in the tree structure such that the size of each tile at said tile level L is larger than that of at least a predefined major portion of said graphic object;

determining an object tile as a tile at said tile level L that overlaps with at least the predefined major portion of said graphic object; and

associating the graphic object with the determined object tile in said tree structure.

2. The method of claim **1** wherein said object tile is the smallest tile in the tree structure that accommodates the entirety of said graphic object.

3. The method of claim **1** wherein said tile level L is determined as the tile level of the smallest tile that whose width is larger than or equal to the diameter of a bounding circle of the graphic object weighted by a first weighting factor C_1.

4. The method of claim **3** wherein said tiles are square tiles, and said determining a tile level L comprises:

iterating from the level having largest tile width to the level having the smallest tile width, to determine the tile level L having the largest tile width W that satisfies $R>C_2W$, where R is the radius of the bounding circle of the graphic object, C_2 is a second weighting factor, and $C_1=1/(4C_2)$.

5. The method of claim **4** wherein said second weighting factor C_2 is 0.25.

6. The method of claim **1** wherein determining the object tile as a tile in said tile level that overlaps with at least the predefined major portion of said graphic object comprises:

determining the object tile as a tile in said tile level that overlaps with the center of a bounding circle of said graphic object.

7. The method of claim **1** further comprising:

determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space;

determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and

loading the determined set of tiles from the first memory device to a second memory device.

8. The method of claim **7** wherein determining a set of tiles comprises:

for each tile in the tree structure:

defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a third weighting factor C_3;

determining if the view port overlaps with said zone; and

marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

9. The method of claim **8** wherein said third weighting factor C_3 is 2.

10. An interactive input system for managing a collaboration space having one or more graphic objects, comprising:

a memory; and

a processing structure functionally coupled to said memory, said processing structure executing computer-executable code stored on a non-transitory computer readable storage device for:

partitioning the collaboration space into a plurality of tiles distributed at a plurality of levels in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at the same level having a same size, each tile at a level either being a leaf node or being subdivided into four smaller tiles at the next level;

determining one or more object tiles, each object tile being a tile of said plurality of tiles and associated with at least one of said one or more graphic objects; and

controlling a first memory area of said memory to store the one or more object tiles therein, each object tile being stored in said first memory area as a separate record that may be independently accessed;

wherein the one or more object tiles are determined by:

for each graphic object,

determining a tile level L in the tree structure such that the size of each tile at said tile level L is larger than that of at least the predefined major portion of said graphic object;

determining an object tile as a tile at said tile level L that overlaps with at least the predefined major portion of said graphic object; and

associating the graphic object with the determined object tile in said tree structure.

11. The interactive input system of claim **10** wherein said processing structure further executes computer-executable code stored on the non-transitory computer readable storage device for:

determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space;

determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and

loading the determined set of tiles from the first memory area to a second memory area.

12. The interactive input system of claim **11** wherein said computer-executable code for determining a set of tiles comprises computer-executable code for:

for each tile in the tree structure:

defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor;

determining if the view port overlaps with said zone; and

marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

13. A non-transitory, computer-readable storage device comprising computer-executable instructions for managing a collaboration space having one or more graphic objects, wherein the instructions, when executed by an interactive input system, cause a processor thereof to perform actions comprising:

partitioning the collaboration space into a plurality of tiles in a tree structure representing a recursive subdivision of the collaboration space, the union of tiles at each level spanning the collaboration space, each tile at the same level having a same size, each tile at a level either being a leaf node or being subdivided into four smaller tiles at the next level;

determining one or more object tiles, each object tile being a tile of said plurality of tiles and associated with at least one of said one or more graphic objects; and

controlling a first memory to store at least the one or more object tiles therein, each object tile being stored in said first memory as a separate record that may be independently accessed;

wherein the one or more object tiles are determined by:

for each graphic object,

determining a tile level L in the tree structure such that the size of each tile at said tile level L is larger than that of at least the predefined major portion of said graphic object;

determining an object tile as a tile at said tile level L that overlaps with at least the predefined major portion of said graphic object; and

associating the graphic object with the determined object tile in said tree structure.

14. The non-transitory, computer-readable storage device of claim **13** wherein said instructions, when executed, further cause the processor to perform actions comprising:

determining the position of a viewport, said viewport displaying a display image of at least a portion of said collaboration space;

determining a set of tiles in said tree structure required for rendering a display image to be displayed in said viewport; and

loading the determined set of tiles from the first memory area to a second memory area.

15. The non-transitory, computer-readable storage device of claim **14** wherein determining a set of tiles comprises:

for each tile in the tree structure:

defining a zone for said tile as an area concentric with said tile with a dimension equal to that of said tile weighted by a weighting factor;

determining if the view port overlaps with said zone; and

marking the tile as a required tile of said set of tiles if the view port overlaps with said zone.

* * * * *